PHYSIOLOGY

LESSONS

IN

ELEMENTARY PHYSIOLOGY.


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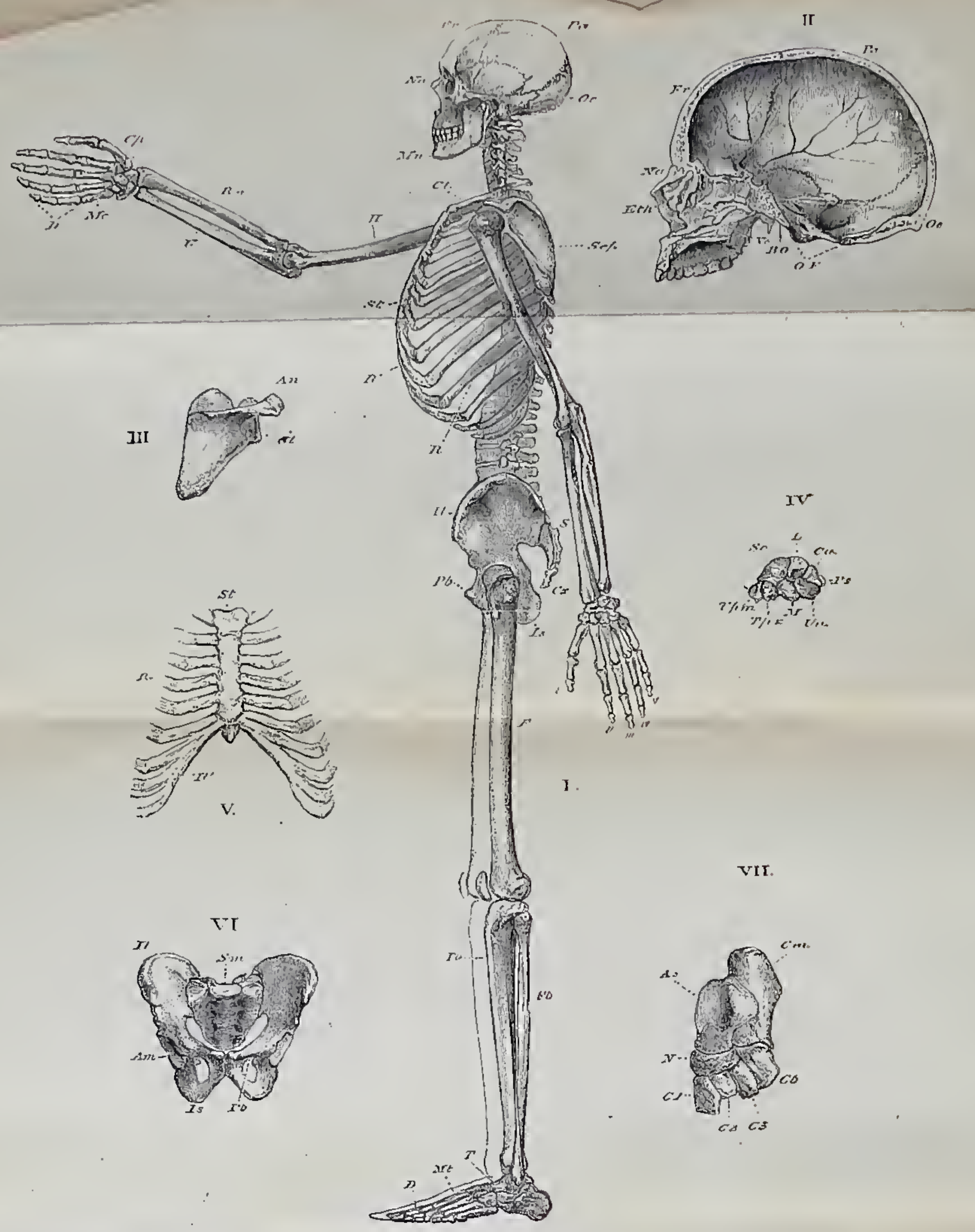

EXPLANATION OF THE PLATE.

[illegible]

Pa. The Parietal bones.
Oc. The Occipital bone.
Mn. The Mandible or Lower Jaw.
St. The Sternum. } In the Thorax.
R. The Ribs. } In the Thorax.
R'. The Cartilages of the Ribs. } In the Thorax.
S. The Sacrum.
Cx. The Coccyx.
Scp. The Scapula, or Shoulder Blade.
Cl. The Clavicle, or Collar Bone.
H. The Humerus. } In the Arm.
Ra. The Radius. } In the Arm.
U. The Ulna. } In the Arm.
Cp. The Carpus.

I, II, III, IV, V. The Thumb, or Pollex, and the succeeding Fingers.
Il. The Ilium. } Which together form the Haunch bone, or Os innominatum.
Pb. The Pubis. } Which together form the Haunch bone, or Os innominatum.
Is. The Ischium. } Which together form the Haunch bone, or Os innominatum.
F. The Femur. } In the Leg.
Tb. The Tibia. } In the Leg.
Fb. The Fibula. } In the Leg.
T. The Tarsus. } In the Leg.
Mt. The Metatarsus. } In the Leg.
D. The Phalanges of the Toes, or Digits of the Foot. } In the Leg.

Fig. II.—Longitudinal and Vertical Section of the Skull.
The section passes a little to the left of the middle line.

The letters as before, except—
Eth. The Ethmoid bone.
Vo. The Vomer.
B.O. Part of the Occipital bone.
O.F. The Occipital Foramen.
The branching lines are the impressions left by the arteries of the membranes of the brain upon the inner surface of the wall of the cavity, which lodges the cerebrum.

Fig. III.—The Right Scapula.

An. Acromion process.
Gl. Glenoidal cavity.

Fig. IV.—The Dorsal Aspect of the Bones of the Carpus of the Left Hand.

Sc. Scaphoides.
Tpm. Trapezium.
L. Semilunare.
Tpz. Trapezoides.
Cu. Cuneiforme.
M. Magnum.
Ps. Pisiforme.
Un. Unciforme.

Fig. V.

A front view of the Sternum, *St.*, with the Cartilages of the Ribs, *R'*, and part of the Ribs themselves. *R.*

Fig. VI.—A Front View of the Pelvis.

Sm. The Sacrum.
Am. The Acetabulum.
Il. Pb. Is. as before.

Fig. VII.—The Dorsal aspect of the Tarsus of the Left Foot.

Cm. Calcaneum
As. Astragalus.
N. Naviculare.
C^1, C^2, C^3. The three Cuneiform bones.
Cb. The Cuboid.

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ELEMENTARY PHYSIOLOGY.

BY

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PREFACE TO THE SECOND EDITION.

The present edition of the "Lessons in Elementary Physiology," has been very carefully revised. A few woodcuts have been added; others have been replaced by better ones, as in the case of the figures of the retina, which embody the results of Schulze's latest researches.

Some additions (but as few as possible, lest the book should insensibly lose its elementary character) have been made; among the most important I count the very useful "Table of Anatomical and Physiological Constants" drawn up for me by Dr. Michael Foster, for whose friendly aid I am again glad to express my thanks.

It will be well for those who attempt to study Elementary Physiology, to bear in mind the important truth that the knowledge of science which is attainable by mere reading, though infinitely better than ignorance, is knowledge of a very different kind from that which arises from direct contact with fact; and that the worth of the pursuit of science as an intellectual discipline is almost lost by those who seek it only in books, As the majority of the readers of these Lessons will assuredly have no opportunity of studying anatomy or physiology upon the human subject, these remarks may seem discouraging. But they are not so in reality. For the purpose of acquiring a practical, though elementary, acquaintance with physiological anatomy and histology, the organs and tissues of the commonest domestic animals afford ample materials. The principal points in the structure and mechanism of the heart, the lungs, the kidneys, or the eye, of man, may be perfectly illustrated by the corresponding parts of a sheep; while the phenomena of the circulation, and many of the most important properties of living tissues, are better shown by the common frog than by any of the higher animals.

Under these circumstances there really is no reason why the teaching of elementary physiology should not be made perfectly sound and thorough. But it should be remembered that unless the learner has previously acquired a knowledge of the elements of Physics and of Chemistry, his path will be beset with difficulties and delays.

T. H. H.

LONDON, *July* 1868.

PREFACE TO THE FIRST EDITION.

The following "Lessons in Elementary Physiology" are primarily intended to serve the purpose of a text-book for teachers and learners in boys' and girls' schools.

My object in writing them has been to set down, in plain and concise language, that which any person who desires to become acquainted with the principles of Human Physiology may learn, with a fair prospect of having but little to unlearn as our knowledge widens.

It is only by inadvertence, or from an error in judgment, therefore, that the book contains any statement, or doctrine, which cannot be regarded as the common property of all physiologists. I have endeavoured simply to play the part of a sieve, and to separate the well-established and the essential from the doubtful and the unimportant portions of the vast mass of knowledge and opinion we call Human Physiology.

The originals of the woodcuts are, for the most part, to be found in the works of Bourgery, Gray, Henle, and Kölliker. A few are new.

I am particularly indebted to my accomplished friend, Dr. Michael Foster, for the pains and trouble he has bestowed upon the Lessons in their passage through the press.

THE ROYAL SCHOOL OF MINES, LONDON.
October 1866.

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LESSON I.

A GENERAL VIEW OF THE STRUCTURE AND FUNCTIONS OF THE HUMAN BODY.

1. THE body of a living man performs a great diversity of actions, some of which are quite obvious; others require more or less careful observation; and yet others can be detected only by the employment of the most delicate appliances of science.

Thus, some part of the body of a living man is plainly always in motion. Even in sleep, when the limbs, head, and eyelids may be still, the incessant rise and fall of the chest continue to remind us that we are viewing slumber and not death.

But a little more careful observation is needed to detect the motion of the heart; or the pulsation of the arteries; or the changes in the size of the pupil of the eye with varying light; or to ascertain that the air which is breathed out of the body is hotter and damper than the air which is taken in by breathing.

And lastly, when we try to ascertain what happens in the eye when that organ is adjusted to different distances: or what in a nerve when it is excited: or of what materials flesh and blood are made: or in virtue of what mechanism it is that a sudden pain makes one start—we have to call into operation all the methods of inductive and deductive logic; all the resources of physics and chemistry; and all the delicacies of the art of experiment.

2. The sum of the facts and generalizations at which we arrive by these various modes of inquiry, be they simple or be they refined, concerning the actions of the body and the manner in which those actions are brought about, constitutes the science of Human Physiology. An elementary outline of this science, and of so much anatomy as is incidentally necessary, is the subject of the following Lessons; of which I shall devote the present to an account of so much of the structure and such of the actions (or, as they are technically called, "functions") of the body, as can be ascertained by easy observation; or might be so ascertained if the bodies of men were as easily procured, examined, and subjected to experiment, as those of animals.

3. Suppose a chamber with walls of ice, through which a current of pure ice-cold air passes, the walls of the chamber will of course remain unmelted.

Now, having weighed a healthy living man with great care, let him walk up and down the chamber for an hour. In doing this he will obviously exercise a great amount of mechanical force; as much, at least, as would be required to lift his weight as high and as often as he has raised himself at every step. But, in addition, a certain quantity of the ice will be melted, or converted into water; showing that the man has given off heat in abundance. Furthermore, if the air which enters the chamber be made to pass through lime-water, it will cause no cloudy white precipitate of carbonate of lime, because the quantity of carbonic acid in ordinary air is so small as to be inappreciable in this way. But if the air which passes out is made to take the same course, the lime-water will soon become milky, from the precipitation of carbonate of lime, showing the presence of carbonic acid, which, like the heat, is given off by the man.

Again, even if the air be quite dry as it enters the chamber, that which is breathed out of the man, and that which is given off from his skin, will exhibit clouds of vapour; which vapour, therefore, is derived from the body.

After the expiration of the hour during which the experiment has lasted, let the man be released and weighed once more. He will be found to have lost weight.

Thus a living, active, man constantly exerts *mechanical force*, gives off *heat*, evolves *carbonic acid* and *water*, and undergoes a *loss of substance*.

4. Plainly, this state of things could not continue for an unlimited period, or the man would dwindle to nothing. But long before the effects of this gradual diminution of substance become apparent to a bystander, they are felt by the subject of the experiment in the form of the two imperious sensations called hunger and thirst. To still these cravings, to restore the weight of the body to its former amount, to enable it to continue giving out heat, water and carbonic acid, at the same rate, for an indefinite period, it is absolutely necessary that the body should be supplied with each of three things, and with three only. These are, firstly, fresh air; secondly, drink—consisting of water in some shape

or other, however much it may be adulterated; thirdly, food. That compound known to chemists as *protein,* and which contains carbon, hydrogen, oxygen, and nitrogen, must form a part of this food, if it is to sustain life indefinitely; and fatty, starchy, or saccharine matters ought to be contained in the food, if it is to sustain life conveniently.

5. A certain proportion of the matter taken in as food either cannot be, or at any rate is not, used; and leaves the body, as *excrementitious matter*, in the condition in which it entered it, without ever being incorporated with its substance. But, under healthy conditions, and when only so much food as is necessary is taken, no important proportion of either protein matter, or fat, or starchy or saccharine food, as such, passes out of the body by this, or any other channel. Almost everything that leaves the body, in fact, does so either in the form of *water*, or of *carbonic acid*, or of a third substance called *urea*, or of certain *saline* compounds.

Chemists have determined that these products which are thrown out of the body and are called *excretions*, contain, if taken altogether, far more oxygen than the food and water taken into the body. Now, the only possible source whence the body can obtain oxygen, except from food and water, is the air which surrounds it.* And careful investigation of the air which leaves the chamber in the imaginary experiment described above would show, not only that it has gained carbonic acid *from* the man, but

* Fresh country air contains in every 100 parts nearly 21 of oxygen and 79 of nitrogen gas, together with a small fraction of a part of carbonic acid, and a variable proportion of watery vapour and ammonia. (See Lesson IV. § 11.)

that it has lost *oxygen* in equal or rather greater amount *to* him.

6. Thus, if a man is neither gaining nor losing weight, the sum of the weights of all the substances above enumerated which leave the body ought to be exactly equal to the weight of the food and water which enter it, together with that of the oxygen which it absorbs from the air. And this is proved to be the case.

Hence it follows that a man, in health, and "neither gaining nor losing flesh," is *incessantly* oxidating and wasting away, and *periodically* making good the loss. So that if he could be confined in the scale-pan of a delicate spring balance, like that used for weighing letters, in his average condition, the scale-pan would descend at every meal and ascend in the intervals, oscillating to equal distances on each side of the average position, which would never be maintained for longer than a few minutes. There is, therefore, no such thing as a stationary condition of the weight of the body, and what we call such is simply a condition of variation within narrow limits —a condition in which the gains and losses of the numerous daily transactions of the economy balance one another.

7. Suppose this diurnally-balanced physiological state to be reached, it can be maintained only so long as the quantity of the mechanical work done, and of heat, or other force, evolved, remains absolutely unchanged.

Let such a physiologically-balanced man lift a heavy body from the ground, and the loss of weight which he would have undergone without that exertion will be immediately increased by a definite amount, which cannot be made good unless a proportionate amount of extra food be supplied to him. Let the temperature of the air fall, and the same result will occur, if his body remains as warm as before.

On the other hand, diminish his exertion and lower his production of heat, and either he will gain weight, or some of his food will remain unused.

Thus, in a properly nourished man, a stream of food is constantly entering the body in the shape of complex compounds containing comparatively little oxygen; as constantly, the elements of the food (whether before or after they have formed part of the living substance) are leaving the body, combined with more oxygen. And the incessant breaking down and oxidation of the complex compounds which enter the body are definitely proportioned to the amount of force the body exerts, whether in the shape of heat or otherwise: just in the same way as the amount of work to be got out of a steam-engine, and the amount of heat it and its furnace give off, bear a strict proportion to its consumption of fuel.

8. From these general considerations regarding the nature of life, considered as physiological work, we may turn for the purpose of taking a like broad survey of the apparatus which does the work. We have seen the general performance of the engine, we may now look at its build.

The human body is obviously separable into *head*, *trunk*, and *limbs*. In the head, the brain-case, or *skull*, is distinguishable from the *face*. The trunk is naturally divided into the chest or *thorax*, and the *abdomen* or belly. Of the limbs there are two pairs—the upper, or *arms*, and the lower, or *legs*; and legs and arms again are subdivided by their joints into parts which obviously exhibit a rough correspondence—*thigh* and *upper arm, leg* and *fore-arm, ankle* and *wrist, fingers* and *toes,* plainly answering to one another. And the two last, in fact, are so similar that they receive the same name of *digits;* while the several joints of the fingers and toes have the common denomination of *phalanges.*

The whole body thus composed (without the viscera) is seen to be bilaterally symmetrical; that is to say, if it were split lengthways by a great knife, which should be made to pass along the middle line of both the dorsal and ventral (or back and front) aspects, the two halves would almost exactly resemble one another.

9. One half of the body, divided in the manner described (Fig. 1, A), would exhibit, in the trunk, the cut faces of thirty-three bones, joined together by a very strong and tough substance into a long column, which lies much nearer the *dorsal* (or back) than the *ventral* (or front) aspect of the body. The bones thus cut through are called the *bodies* of the *vertebræ.* They separate a long, narrow canal, called the *spinal canal,* which is placed upon their dorsal side, from the spacious chamber of the chest and abdomen, which lies upon their ventral side. There is no direct communication between the dorsal canal and the ventral cavity.

The spinal canal contains a long white cord—the *spinal cord*—which is an important part of the nervous system. The ventral chamber is divided into the two subordinate cavities of the thorax and abdomen by a remarkable, partly fleshy and partly membranous, partition, the *diaphragm* (Fig. 1, *D*), which is concave towards the abdomen, and convex towards the thorax. The *alimentary canal* (Fig. 1, *Al.*) traverses these cavities from one end to the other, piercing the diaphragm. So does a long double series of distinct masses of nervous substance, which are called *ganglia*, are connected together by nervous cords, and constitute the so-called *sympathetic* (Fig. 1, *Sy.*). The abdomen contains, in addition to these parts, the two *kidneys*, one placed against each side of the vertebral column, the *liver*, the *pancreas* or "sweetbread," and the *spleen*. The thorax incloses, besides its segment of the alimentary canal and of the sympathetic, the *heart* and the two *lungs*. The latter are placed one on each side of the heart, which lies nearly in the middle of the thorax.

Where the body is succeeded by the head, the uppermost of the thirty-three vertebral bodies is followed by a continuous mass of bone, which extends through the whole length of the head, and, like the spinal column, separates a dorsal chamber from a ventral one. The dorsal chamber, or *cavity of the skull*, opens into the spinal canal. It contains a mass of nervous matter called the *brain*, which is continuous with the spinal cord, the brain and the spinal cord together constituting what is termed the *cerebro-spinal* axis (*C.S.*, *C.S.*). The ventral chamber, or *cavity of the face*, is almost entirely occupied by the *mouth* and *pharynx*, into which last the upper end of the alimentary canal (called gullet or *œsophagus*) opens.

10. Thus, the study of a longitudinal section shows us that the human body is a double tube, the two tubes being completely separated by the spinal column and the bony axis of the skull, which form the floor of the one tube and the roof of the other. The dorsal tube contains the cerebro-spinal axis; the ventral, the alimentary canal, the sympathetic nervous system, and the heart, besides other organs.

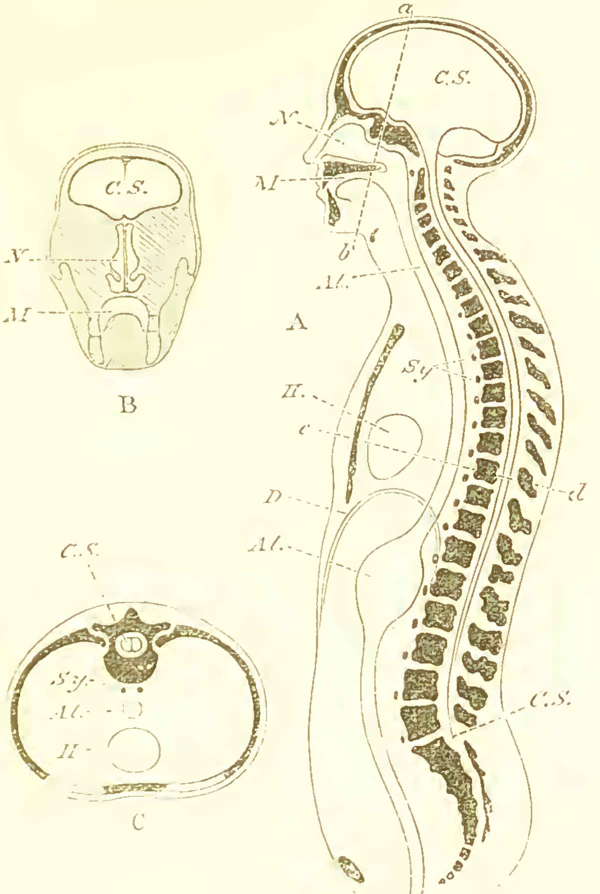

Fig. 1.

A, a diagrammatic section of the human body taken vertically through the median plane. *C.S.* the cerebro-spinal nervous system; *N*, the cavity of the nose; *M*, that of the mouth; *Al.*, *Al.* the alimentary canal represented as a simple straight tube; *H*, the heart; *D.* the diaphragm; *Sy.* the sympathetic ganglia.

B, a transverse vertical section of the head taken parallel with the line *a b*; letters as before.

C, a transverse section taken along the line *c d*; letters as before.

Transverse sections, taken perpendicularly to the axis of the vertebral column, or to that of the skull, show still more clearly that this is the fundamental structure of the human body, and that the great apparent difference between the head and the trunk is due to the different size of the dorsal cavity relatively to the ventral. In the head the former cavity is very large in proportion to the size of the latter (Fig. 1, B); in the thorax, or abdomen, it is very small (Fig. 1, C).

The limbs contain no such chambers as are found in the body and the head; but, with the exception of certain branching tubes filled with fluid, which are called *blood-vessels* and *lymphatics,* are solid, or semi-solid, throughout.

11. Such being the general character and arrangement of the parts of the human body, it will next be well to consider into what constituents it may be separated by the aid of no better means of discrimination than the eye and the anatomist's knife.

With no more elaborate aids than these, it becomes easy to separate that tough membrane which invests the whole body, and is called the skin, or *integument,* from the parts which lie beneath it. Furthermore, it is readily enough ascertained that this integument consists of two portions: a superficial layer, which is constantly being shed in the form of powder or scales, composed of minute particles of horny matter, and is called the *epidermis;* and a deeper part, the *dermis,* which is dense and fibrous. The epidermis, if wounded, neither gives rise to pain nor bleeds. The dermis, under like circumstances, is very tender, and bleeds freely. A practical distinction is drawn between the two in shaving, in the course of which operation the razor ought to cut only epidermic structures; for if it go a shade deeper, it gives rise to pain and effusion of blood.

The skin can be readily enough removed from all parts of the exterior, but at the margins of the apertures of the body it seems to stop, and to be replaced by a layer which is much redder, more sensitive, bleeds more readily, and is rendered moist by giving out a more or less tenacious fluid, called *mucus*. Hence, at these apertures, the integument is said to stop, and to be replaced by *mucous membrane*, which lines all those interior cavities, such as the alimentary canal, into which the apertures open. But, in truth, the integument does not come to an end at these points, but is directly continued into the mucous membrane, which last is simply an integument of greater delicacy, but consisting fundamentally of the same two layers, a deep, fibrous, sanguine, and nervous layer, and a superficial, horny, insensible, and bloodless one, now called the *epithelium*. Thus every part of the body might be said to be contained between the walls of a double bag, formed by the epidermis, which invests the outside of the body, and the epithelium, its continuation, which lines the internal cavities.

12. The dermis, and the deep, sanguine layer, which answers to it in the mucous membranes, are chiefly made up of a filamentous substance, which yields abundant *gelatine* on being boiled, and is the matter which tans when hide is made into leather. This is called *areolar*, *fibrous*, or, better, *connective* tissue.* The last name is the best, because this tissue is the great connecting medium by which the

* Every such constituent of the body, as epidermis, cartilage, or muscle, is called a "tissue."

different parts of the body are held together. Thus it passes from the dermis between all the other organs, ensheathing the muscles, coating the bones and cartilages, and eventually reaching and entering into the mucous membranes. And so completely and thoroughly does the connective tissue permeate almost all parts of the body, that if every other tissue could be dissected away, a complete model of all the organs would be left composed of this tissue. Connective tissue varies very much in character; sometimes being very soft and tender, at others—as in the tendons and ligaments, which are almost wholly composed of it—attaining great strength and density.

13. Among the most important of the tissues imbedded in and ensheathed by the connective tissue, are some the presence and action of which can be readily determined during life.

If the upper arm of a man whose arm is stretched out be tightly grasped by another person, the latter, as the man bends up his fore-arm, will feel a great soft mass which lies at the fore part of the upper arm, swell, harden, and become prominent. As the arm is extended again, the swelling and hardness vanish.

On removing the skin, the body which thus changes its configuration is found to be a mass of red flesh, sheathed in connective tissue. The sheath is continued at each end into a tendon, by which the muscle is attached, on the one hand, to the shoulder-bone, and, on the other, to one of the bones of the fore-arm. This mass of flesh is the *muscle* called *biceps*, and it has the peculiar property of changing its dimensions—shortening and becoming thick in proportion to its decrease in length—when influenced by the will as well as by some other causes.* It is by reason of this property that muscular tissue becomes the great motor agent of the body; the muscles being so disposed between the systems of levers which support the body, that their shortening necessitates the motion of one lever upon another.

14. These levers form part of the system of hard tissues which constitute the *skeleton*. The softer of these are the *cartilages*, composed of a dense, firm substance, ordinarily known as "gristle." The harder are the *bones*, which are masses either of cartilage, or of connective tissue, hardened by being impregnated with *phosphate* and *carbonate of lime*. They are animal tissues which have become, in a manner, naturally petrified; and when the salts of lime are extracted, as they may be, by the action of acids, a model of the bone in soft and flexible animal matter remains.

More than 200 separate bones are ordinarily reckoned in the human body, though the actual number of distinct bones varies at different periods of life, many bones which are separate in youth becoming united together in old age. Thus there are originally, as we have seen, thirty-three separate bodies of vertebræ in the spinal column, and the upper twenty-four of these commonly remain distinct throughout life. But the twenty-fifth, twenty-sixth, twenty-seventh, twenty-eighth, and twenty-ninth early unite into one great bone, called the *sacrum;* and the four remaining vertebræ often run into one bony mass called the *coccyx*. In early adult life, the skull contains twenty-two naturally separate bones, but in youth the number is much greater,

* Such causes are called *stimuli*.

and in old age far less. Twenty-four ribs bound the chest laterally, twelve on each side, and most of them are connected by cartilages with the breast-bone. In the girdle which supports the shoulder, two bones are always distinguishable as the *scapula* and the *clavicle.* The *pelvis,* to which the legs are attached, consists of two separate bones called the *ossa innominata* in the adult; but each *os innominatum* is separable into three (called *pubis, ischium,* and *ilium*) in the young. There are thirty bones in each of the arms, and the same number in each of the legs, counting the *patella,* or knee pan.

All these bones are fastened together by ligaments, or by cartilages; and, where they play freely over one another, a coat of cartilage furnishes the surfaces which come into contact. The free surfaces of those articular cartilages which enter into a joint, again, are lined by a delicate *synovial* membrane, which secretes a lubricating fluid—the *synovia.*

15. Though the bones of the skeleton are all strongly enough connected together by ligaments and cartilages, the joints play so freely, and the centre of gravity of the body, when erect, is so high up, that it is impossible to make a skeleton, or a dead body, support itself in the upright position. That position, easy as it seems, is the result of the contraction of a multitude of muscles which oppose and balance one another. Thus, the foot affording the surface of support, the muscles of the calf (Fig. 2, I) must contract, or the legs and body would fall forward. But this action tends to bend the leg; and to neutralize this and keep the leg straight, the great muscles in front of the thigh (Fig. 2, 2) must come into play. But these, by the same action, tend to bend the body forward on

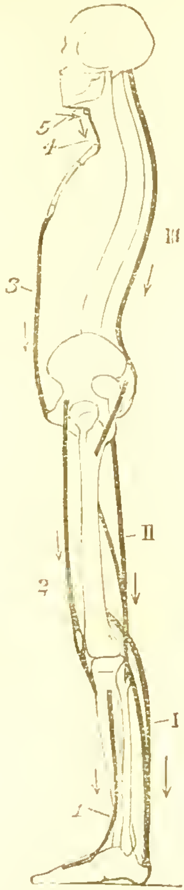

FIG. 2.—A DIAGRAM ILLUSTRATING THE ATTACHMENTS OF SOME OF THE MOST IMPORTANT MUSCLES WHICH KEEP THE BODY IN THE ERECT POSTURE.

I. The muscles of the calf. II. Those of the back of the thigh. III. Those of the spine, which tend to keep the body from falling forward.

1. The muscles of the front of the leg. 2 Those of the front of the thigh. 3. Those of the front of the abdomen. 4, 5. Those of the front of the neck, which tend to keep the body from falling backwards. The arrows indicate the direction of action of the muscles, the foot being fixed.

the legs; and if the body is to be kept straight, they must be neutralized by the action of the muscles of the buttocks and of the back (Fig. 2, III).

The erect position, then, which we assume so easily and without thinking about it, is the result of the combined and accurately proportioned action of a vast number of muscles. What is it that makes them work together in this way?

16. Let any person in the erect position receive a violent blow on the head, and you know what occurs. On the instant he drops prostrate, in a heap, with his limbs relaxed and powerless. What has happened to him? The blow may have been so inflicted as not to touch a single muscle of the body; it may not cause the loss of a drop of blood: and, indeed, if the "concussion," as it is called, has not been too severe, the sufferer, after a few moments of unconsciousness, will come to himself, and be as well as ever again. Clearly, therefore, no permanent injury has been done to any part of the body, least of all to the muscles, but an influence has been exerted upon a something which governs the muscles. And this influence may be the effect of very subtle causes. A strong mental emotion, and even a very bad smell, will, in some people, produce the same effect as a blow.

These observations might lead to the conclusion that it is the mind which directly governs the muscles, but a little further inquiry will show that such is not the case. For people have been so stabbed, or shot in the back, as to cut the spinal cord, without any considerable injury to other parts: and then they have lost the power of standing upright as much as before, though their minds may have remained perfectly clear. And not only have they lost the power of standing upright under these circumstances, but they no longer retain any power of either feeling what is going on in their legs, or, by an act of their volition, causing motion in them.

17. And yet, though the mind is thus cut off from the lower limbs, a controlling and governing power over them still remains in the body. For, if the soles of the disabled feet be tickled, though no sensation will reach the body, the legs will be jerked up, just as would be the case in an uninjured person. Again, if a series of galvanic shocks be sent along the spinal cord, the legs will perform movements even more powerful than those which the will could produce in an uninjured person. And, finally, if the injury is of such a nature that the cord is crushed or profoundly disorganized, all these phenomena cease; tickling the soles, or sending galvanic shocks along the spine, will produce no effect upon the legs.

By examinations of this kind carried still further, we arrive at the remarkable result that the brain is the seat of all sensation and mental action, and the primary source of all voluntary muscular contraction; while the spinal cord is capable of receiving an impression from the exterior, and converting it not only into a simple muscular contraction, but into a combination of such actions.

Thus, in general terms, we may say of the cerebro-spinal nervous centres, that they have the power, when they receive certain impressions from without, of giving rise to simple, or combined, muscular contractions.

18. But you will further note that these impressions from without are of very different characters.

Any part of the surface of the body may be so affected as to give rise to the sensations of contact, or of heat or cold; and any or every substance is able, under certain circumstances, to produce these sensations. But only very few and comparatively small portions of the bodily framework are competent to be affected, in such a manner, as to cause the sensations of taste or of smell, of sight, or of hearing: and only a few substances, or particular kinds of vibrations, are able so to affect those regions. These very limited parts of the body, which put us in relation with particular kinds of substances, of forms of force, are what are termed *sensory organs*. There are two such organs for sight, two for hearing, two for smell, and one, or more strictly speaking two, for taste.

19. And now that we have taken this brief view of the structure of the body, of the organs which support it, of the organs which move it, and of the organs which put it in relation with the surrounding world, or, in other words, enable it to move in harmony with influences from without, we must consider the means by which all this wonderful apparatus is kept in working order.

All work, as we have seen, implies waste. The work of the nervous system and that of the muscles, therefore, implies consumption either of their own substance, or of something else And as the organism can make nothing, it must possess the means of obtaining from without that which it wants, and of throwing off from itself that which it wastes; and we have seen that, in the gross, it does these things. The body feeds, and it excretes. But we must now pass from the broad fact to the mechanism by which the fact is brought about.

The organs which convert food into nutriment are the organs of *alimentation;* those which distribute nutriment all over the body are organs of *circulation;* those which get rid of the waste products are organs of *excretion.*

20. The organs of alimentation are the mouth, pharynx, gullet, stomach, and intestines, with their appendages. What they do is, first to receive and grind the food. They then act upon it with chemical agents, of which they possess a store which is renewed as fast as it is wasted; and in this way separate it into a fluid containing nutritious matters in solution or suspension, and innutritious dregs or *fæces.*

21. A system of minute tubes, with very thin walls, termed *capillaries,* is distributed through the whole organism except the epidermis and its products, the epithelium, the cartilages, and the substance of the teeth. On all sides, these tubes pass into others, which are called *arteries* and *veins;* while these, becoming larger and larger, at length open into the *heart,* an organ which, as we have seen, is placed in the thorax. During life, these tubes, and the chambers of the heart, with which they are connected, are all full of liquid, which is, for the most part, that red fluid with which we are all familiar as *blood.*

The walls of the heart are muscular, and contract rhythmically, or at regular intervals. By means of these contractions the blood which its cavities contain is driven in jets out of these cavities into the arteries, and thence into the capillaries, whence it returns by the veins back into the heart.

This is the *circulation of the blood.*

22. Now the fluid containing the dissolved or suspended nutritive matters which are the result of the

process of digestion, traverses the very thin layer of soft and permeable tissue which separates the cavity of the alimentary canal from the cavities of the innumerable capillary vessels which lie in the walls of that canal, and so enters the blood, with which those capillaries are filled. Whirled away by the torrent of the circulation, the blood, thus charged with nutritive matter, enters the heart, and is thence propelled into the organs of the body. To these organs it supplies the nutriment with which it is charged; from them it takes their waste products, and, finally, returns by the veins, loaded with useless and injurious excretions, which sooner or later take the form of water, carbonic acid, and urea.

23. These excretionary matters are separated from the blood by the *excretory organs*, of which there are three—the *skin*, the *lungs*, and the *kidneys*.

Different as these organs may be in appearance, they are constructed upon one and the same principle. Each, in ultimate analysis, consists of a very thin sheet of tissue, like so much delicate blotting-paper, the one face of which is free, or lines a cavity in communication with the exterior of the body, while the other is in contact with the blood which has to be purified.

The excreted matters are, as it were, strained from the blood, through this delicate layer of filtering tissue, and on to its free surface, whence they make their escape.

Every one of these organs eliminates the same products, viz. water, carbonic acid, and urea, or some nitrogenous compound of like import. But they eliminate them in various proportions—the skin giving off much water, little carbonic acid, and still less urea; the lungs giving off much water, much carbonic acid, and a minimum of urea, or ammonia (which is one of the products of the decomposition of urea); the kidneys separating much water, much urea, and a minimum of carbonic acid.

24. Finally, the lungs play a double part, being not merely eliminators of waste, or excretionary, products, but importers into the economy of a substance which is not exactly either food or drink, but something as important as either,—to wit, *oxygen.* It is oxygen which is the great sweeper of the economy. Introduced by the blood, into which it is absorbed, into all corners of the organism, it seizes upon those organic molecules which are disposable, lays hold of their elements, and combines with them into the new and simpler forms, carbonic acid, water, and urea.

The oxidation, or in other words, the *burning,* of these effete matters, gives rise to an amount of heat which is as efficient as a fire to raise the blood to a temperature of about 100°; and this hot fluid, incessantly renewed in all parts of the economy by the torrent of the circulation, warms the body, as a house is warmed by a hot-water apparatus.

25. But these alimentary, distributive or circulatory, excretory, and combustive processes would be worse than useless if they were not kept in strict proportion one to another. If the state of physiological balance is to be maintained, not only must the quantity of aliment taken be at least equivalent to the quantity of matter excreted; but that aliment must be distributed with due rapidity to the seat of each local waste. The circulatory system is the commissariat of the physiological army.

Again, if the body is to be maintained at a tolerably even temperature, while that of the air is constantly varying, the condition of the hot-water apparatus must be most carefully regulated.

In other words, a *combining organ* must be added to the organs already mentioned, and this is found in the nervous system, which not only possesses the function already described of enabling us to move our bodies and to know what is going on in the external world; but makes us aware of the need of food, enables us to discriminate nutritious from innutritious matters, and to exert the muscular actions needful for seizing, killing, and cooking; guides the hand to the mouth, and governs all the movements of the jaws and of the alimentary canal. By it, the working of the heart is properly adjusted and the calibres of the distributing pipes are regulated, so as indirectly to govern the excretory and combustive processes. And these are more directly affected by other actions of the nervous system.

26. The various functions which have been thus briefly indicated constitute the greater part of what are called the *vital actions* of the human body, and, so long as they are performed, the body is said to possess *life*. The cessation of the performance of these functions is what is ordinarily called *death*.

But there are really several kinds of death, which may, in the first place, be distinguished from one another under the two heads of *local* and of *general* death.

27. *Local death* is going on at every moment, and in most, if not in all, parts of the living body. Individual cells of the epidermis and of the epithelium are incessantly dying and being cast off, to be replaced by others which are, as constantly, coming into sepa-

rate existence. The like is true of blood-corpuscles, and probably of many other elements of the tissues.

This form of local death is insensible to ourselves, and is essential to the due maintenance of life. But, occasionally, local death occurs on a larger scale, as the result of injury, or as the consequence of disease. A burn, for example, may suddenly kill more or less of the skin; or part of the tissues of the skin may die, as in the case of the slough which lies in the midst of a boil; or a whole limb may die, and exhibit the strange phenomena of *mortification.*

The local death of some tissues is followed by their regeneration. Not only all the forms of epidermis and epithelium, but nerve, connective tissue, bone, and, at any rate, some muscles, may be thus reproduced, even on a large scale. Cartilage once destroyed is not restored.

28. *General death* is of two kinds, *death of the body as a whole*, and *death of the tissues*. By the former term is implied the absolute cessation of the functions of the brain, of the circulatory, and of the respiratory organs; by the latter, the entire disappearance of the vital actions of the ultimate structural constituents of the body. When death takes place, the body, as a whole, dies first, the death of the tissues sometimes not occurring until after a considerable interval.

Hence it is that, for some little time after what is ordinarily called death, the muscles of an executed criminal may be made to contract by the application of proper stimuli. The muscles are not dead, though the man is.

29. The modes in which death is brought about appear at first sight to be extremely varied. We speak of natural death by old age, or by some of the

endless forms of disease; of violent death by starvation, or by the innumerable varieties of injury, or poison. But, in reality, the immediate cause of death is always the stoppage of the functions of one of three organs; the cerebro-spinal nervous centre, the lungs, or the heart. Thus, a man may be instantly killed by such an injury to a part of the brain which is called the *medulla oblongata* (see Lesson XI.) as may be produced by hanging, or breaking the neck.

Or death may be the immediate result of suffocation by strangulation, smothering, or drowning,—or, in other words, of stoppage of the respiratory functions.

Or, finally, death ensues at once when the heart ceases to propel blood. These three organs, the brain, the lungs, and the heart, have been fancifully termed the *tripod of life.*

In ultimate analysis, however, life has but two legs to stand upon, the lungs and the heart, for death through the brain is always the effect of the secondary action of the injury to that organ upon the lungs or the heart. The functions of the brain cease, when either respiration or circulation are at an end. But if circulation and respiration are kept up artificially, the brain may be removed without causing death. On the other hand, if the blood be not aërated, its circulation by the heart cannot preserve life; and, if the circulation be at an end, mere aëration of the blood in the lungs is equally ineffectual for the prevention of death.

30. With the cessation of life, the everyday forces of the inorganic world no longer remain the servants of the bodily frame, as they were during life, but become its masters. Oxygen, the sweeper of the living organism, becomes the lord of the dead body. Atom by atom, the complex molecules of the

tissues are taken to pieces and reduced to simpler and more oxidated substances, until the soft parts are dissipated chiefly in the form of carbonic acid, ammonia, water, and soluble salts, and the bones and teeth alone remain. But not even these dense and earthy structures are competent to offer a permanent resistance to water and air. Sooner or later the animal basis which holds together the earthy salts decomposes and dissolves—the solid structures become friable, and break down into powder. Finally, they dissolve and are diffused among the waters of the surface of the globe, just as the gaseous products of decomposition are dissipated through its atmosphere.

It is impossible to follow, with any degree of certainty, wanderings more varied and more extensive than those imagined by the ancient sages who held the doctrine of transmigration; but the chances are, that sooner or later, some, if not all, of the scattered atoms will be gathered into new forms of life.

The sun's rays, acting through the vegetable world, build up some of the wandering molecules of carbonic acid, of water, of ammonia, and of salts, into the fabric of plants. The plants are devoured by animals, animals devour one another, man devours both plants and other animals; and hence it is very possible that atoms which once formed an integral part of the busy brain of Julius Cæsar may now enter into the composition of Cæsar the negro in Alabama, and of Cæsar the house-dog in an English homestead.

And thus there is sober truth in the words which Shakespeare puts into the mouth of Hamlet—

> "Imperial Cæsar, dead and turned to clay,
> Might stop a hole to keep the cold away;
> Oh that that earth, which kept the world in awe,
> Should patch a wall, t'expel the winter's flaw!"

LESSON II.

THE VASCULAR SYSTEM AND THE CIRCULATION.

1. ALMOST all parts of the body are *vascular;* that is to say, they are traversed by minute and very close-set canals, which open into one another so as to constitute a small-meshed network, and confer upon these parts a spongy texture. The canals, or rather tubes, are provided with distinct but very delicate walls, composed of a structureless membrane, in which at intervals small oval bodies. termed *nuclei*, are imbedded.

These tubes are what are termed the *capillaries.* They vary in diameter from $\frac{1}{1500}$th to $\frac{1}{2000}$th of an inch; they are sometimes disposed in loops, sometimes in long, sometimes in wide, sometimes in narrow meshes; and the diameters of these meshes, or in other words, the interspaces between the capillaries, are sometimes hardly wider than the diameter of a capillary, sometimes many times as wide (Fig. 3, A, B, C, D). These interspaces are occupied by the tissue which the capillaries permeate, so that the ultimate anatomical components of every part of the body are, strictly speaking, outside the vessels, or *extra-vascular.*

But there are certain parts which, in another and broader sense, are also said to be extra-vascular or non-vascular. These are the epidermis and epithelium, the nails and hairs, the substance of the teeth, and the cartilages; which may and do attain a very considerable thickness or length, and yet contain no vessels. However, as we have seen that all the tissues are extra-vascular, these differ only in degree from the rest. The circumstance that all the tissues are outside the vessels by no means interferes with their being bathed by the fluid which is inside the vessels. In fact, the walls of the capillaries are so exceedingly thin that their fluid contents readily

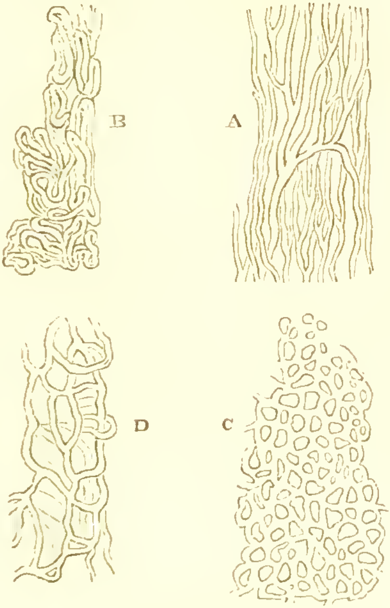

FIG. 3.

A, Capillaries of muscle; B, Looped capillaries of the finger; C, Capillaries of the lungs; D, Of fat.
Magnified about 100 diameters.

exude through the delicate membrane of which they are composed, and irrigate the tissues in which they lie.

2. Of the capillary tubes thus described, one kind contains, during life, the red fluid, *blood,* while the

others are filled with a pale, watery, or milky fluid, termed *lymph*, or *chyle*. The capillaries, which contain blood, are continued on different sides into somewhat larger tubes, with thicker walls, which are the smallest *arteries* and *veins*.

The mere fact that the walls of these vessels are thicker than those of the capillaries constitutes an important difference between the capillaries and the small arteries and veins; for the walls of the latter are thus rendered far less permeable to fluids, and that thorough irrigation of the tissues, which is effected by the capillaries, cannot be performed by them.

Fig. 4.—A minute artery (*a*), ending in (*b*) larger and (*c*) smaller capillaries. *d*, Nuclei imbedded in the walls of the capillaries. Magnified about 200 diameters.

The most important difference between these vessels and the capillaries, however, lies in the circumstance that their walls are not only thicker, but also more complex, being composed of several coats, one of which consists of muscular fibres (Fig. 5, B), which are directed transversely, so as to encircle the artery or vein (as at *a*, Fig. 4). This coat lies in the middle of the thickness of the wall of the vessel; inside it, and lining the cavity of the vessel, is a layer of very delicate, elongated, epithelial cells (Fig. 5, A; Fig. 6, *c*). Outside the muscular layer is a sheath of fibrous tissue (*a*, Fig. 6). The muscular fibres themselves are flattened, spindle-shaped bands, each with an elongated rod-like nucleus in the middle (Fig. 5, B). When these

FIG. 5.

A. Epithelial cells of the arteries. *a*, The nucleus.
B. Muscular fibres of the arteries: the middle one having been treated with acetic acid, shows more distinctly the nucleus *a*. Magnified about 350 diameters.

fibres exercise that power of contraction, or shortening in the long, and broadening in the narrow, directions (which, as was stated in the preceding Lesson, is the special property of muscular tissue), they, of course, narrow the calibre of the vessel, just as squeezing it in any other way would do; and this contraction may go so far as, in some cases, to reduce the cavity of the vessel almost to nothing, and to render it practically impervious.

The state of contraction of these muscles of the small arteries and veins is regulated, like that of other muscles, by their nerves; or in other words, the nerves supplied to the vessels determine whether the passage through these tubes shall be free and wide, or narrow and obstructed. Thus while the small arteries and veins lose the function of directly irrigating the tissues which the capillaries possess, they gain that of regulating the supply of fluid to the irrigators, or capillaries themselves. The contraction, or dilatation, of the arteries which supply a set of capillaries, comes to the same result as lowering or raising the sluice-gates of a system of irrigation-canals.

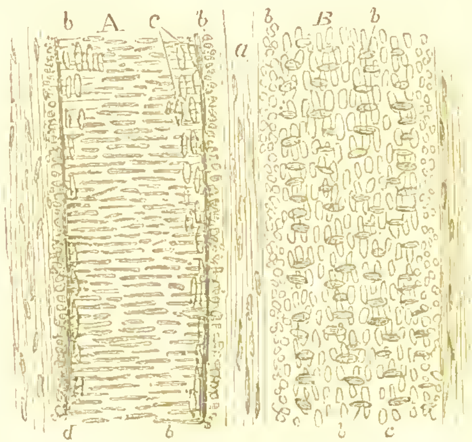

Fig. 6.

A. A small artery.
B. A small vein, both treated with acetic acid: *a*, fibrous coat, *b*, nuclei of the muscular coat; *c*, nuclei of the epithelial coat. Magnified about 300 diameters.

3. The smaller arteries and veins severally unite into, or are branches of, larger arterial or venous trunks, which again spring from still larger ones, and these, at length, communicate by a few principal arterial and venous trunks with the heart.

The smallest arteries and veins, as we have seen, are similar in structure, but the larger arteries and veins differ widely; for the larger arteries have walls so thick and stout that they do not sink together when empty; and this thickness and stoutness arises from the circumstance that, not only is the muscular coat very thick, but that, in addition, a strong coat of highly elastic fibrous substance is developed outside the muscular layer. Thus, when a large artery is pulled out and let go, it stretches and returns to its primitive dimensions almost like a piece of india-rubber.

The larger veins, on the other hand, contain but little of either elastic or muscular tissue. Hence, their walls are thin, and they collapse when empty

This is one great difference between the larger arteries and the veins; the other is the presence of what are termed *valves* in a great many of the veins, especially in those which lie in muscular parts of the body.

4. These valves are pouch-like folds of the inner wall of the vein. The bottom of the pouch is turned towards those capillaries into which the vein opens. The free edge of the pouch is directed the other way, or towards the heart. The action of these pouches is to impede the passage of any fluid from the heart towards the capillaries, while they do not interfere with fluid passing in the opposite direction (Fig. 7). The working of some of these valves may be very

easily demonstrated in the living body. When the arm is bared, blue veins may be seen running from the hand, under the skin, to the upper arm. The

Fig. 7.—Diagrammatic Sections of Veins with Valves.

In the upper, the blood is supposed to be flowing in the direction of the arrow, towards the heart: in the lower, the reverse way. C, capillary side; H, heart side.

diameter of these veins is pretty even, and diminishes regularly towards the hand, so long as the current of the blood, which is running in them, from the hand to the upper arm, is uninterrupted.

But if a finger be pressed upon the upper part of one of these veins, and then passed downwards along it, so as to drive the blood which it contains backwards, sundry swellings, like little knots, will suddenly make their appearance at several points in the length of the vein, where nothing of the kind was visible before. These swellings are simply dilatations of the wall of the vein, caused by the pressure of the blood on that wall, above a valve which opposes its backward progress. The moment the backward impulse ceases the blood flows on again; the valve, swinging back towards the wall of the vein, affords no obstacle to its progress, and the distension caused by its pressure disappears (Fig. 7).

The only arteries which possess valves are the primary trunks—the aorta and pulmonary artery—which spring from the heart, and they will be best considered with the latter organ.

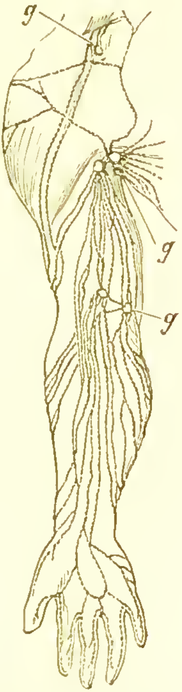

FIG. 8.—THE LYMPHATICS OF THE FRONT OF THE RIGHT ARM.

g Lymphatic glands, or *ganglia*, as they are sometimes called. These *ganglia* are not to be confounded with nervous *ganglia*.

5. Besides the capillary network and the trunks connected with it, which constitute the blood-vascular system, all parts of the body which possess blood capillaries—except the brain and spinal cord, the eyeball, the gristles, tendons, and perhaps the

bones*—also contain another set of what are termed *lymphatic* capillaries, mixed up with those of the blood-vascular system, but not directly communicating with them, and, in addition, differing from the blood capillaries in being connected with larger vessels of only one kind. That is to say, they open only into trunks which carry fluid away from them, there being no large vessels which bring anything to them.

These trunks further resemble the small veins in being abundantly provided with valves which freely allow of the passage of liquid from the lymphatic capillaries, but obstruct the flow of anything the other way. But the lymphatic trunks differ from the veins, in that they do not rapidly unite into larger and larger trunks, which present a continually increasing calibre and allow of a flow without interruption to the heart.

On the contrary, remaining nearly of the same size, they, at intervals, enter and ramify in rounded bodies called *lymphatic glands*, whence new lymphatic trunks arise (Fig. 8). In these glands the lymphatic capillaries and passages are closely interlaced with blood capillaries.

Sooner or later, however, the great majority of the smaller lymphatic trunks pour their contents into a tube, which is about as large as a crow-quill, lies in front of the backbone, and is called the *thoracic duct*. This opens at the root of the neck into the conjoined trunks of the great veins which bring back the blood from the left side of the head and the left arm (Fig. 9). The remaining lymphatics are connected by a common canal with the corresponding vein on the right side.

* It is probable that these exceptions are apparent rather than real, but the question is not yet satisfactorily decided.

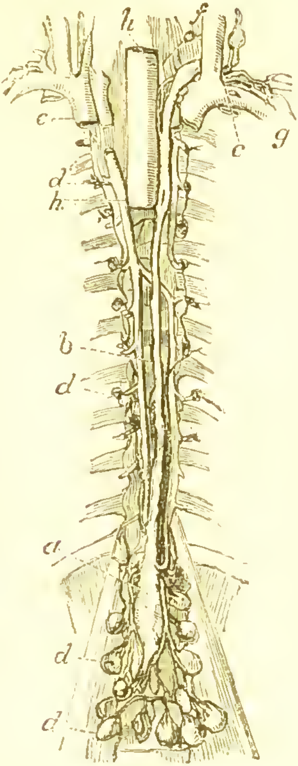

FIG. 9.—THE THORACIC DUCT.

The Thoracic Duct occupies the middle of the figure. It lies upon the spinal column, at the sides of which are seen portions of the ribs. At the bottom of the figure the psoas muscles appear.

a. The receptacle of the chyle; *b*, the trunk of the thoracic duct, opening at *c* into the junction of the left jugular (*f*) and subclavian (*g*) veins as they unite into the left innominate vein; *e*, the right innominate vein formed by the union of the left jugular and subclavian veins; *d*, lymphatic glands placed in the lumbar and intercostal regions; *h h*, the cut œsophagus. Two veins are seen running alongside the lower part of the thoracic duct, and just above its middle, one (the left) crosses under the duct and joins the other. These are the azygos veins.

Where the principal trunks of the lymphatic system open into the veins, valves are placed, which allow of the passage of fluid only from the lymphatic to the vein. Thus the lymphatic vessels are, as it were, a part of the venous system, though, by reason of these valves, the fluid which is contained in the veins cannot get into the lymphatics. On the other hand, every facility is afforded for the passage into the veins of the fluid contained in the lymphatics. Indeed, in consequence of the numerous valves in the lymphatics, every pressure on, and contraction of, their walls, not being able to send the fluid backward, must drive it more or less forward, towards the veins.

6. The lower part of the thoracic duct is dilated, and is termed the *receptacle*, or *cistern*, of the *chyle* (*a*, Fig. 9). In fact, it receives the lymphatics of the intestines, which, though they differ in no essential respect from other lymphatics, are called *lacteals*, because, after a meal containing much fatty matter, they are filled with a milky fluid, which is termed the *chyle*. The lacteals, or lymphatics of the small intestine, not only form networks in its walls, but send blind prolongations into the little velvety processes termed *villi*, with which the mucous membrane of that intestine is beset (see Lesson VI.). The trunks which open into the network lie in the *mesentery* (or membrane which suspends the small intestine to the back wall of the abdomen), and the glands through which these trunks lead are hence termed the *mesenteric glands*.

7. It will now be desirable to take a general view of the arrangement of all these different vessels, and of their relations to the great central organ of the vascular system—the heart (Fig. 10).

All the veins of every part of the body, except the lungs, the heart itself, and certain viscera of the abdomen, join together into larger veins, which, sooner or later, open into one of two great trunks (Fig. 10, *V.C.S. V.C.I.*) termed the *superior* and the *inferior vena cava*, which debouch into the upper, or broad end of the right half of the heart.

All the arteries of every part of the body, except the lungs, are more or less remote branches of one great trunk—the *aorta* (Fig. 10, *Ao.*), which springs from the lower division of the left half of the heart.

The arteries of the lungs are branches of a great trunk (Fig. 10, *P.A.*) springing from the lower division of the right side of the heart. The veins of the lungs, on the contrary, open by four trunks into the upper part of the left side of the heart (Fig. 10, *P.V.*).

Thus the venous trunks open into the upper division of each half of the heart—those of the body in general into that of the right half; those of the lungs into the upper division of the left half; while the arterial trunks spring from the lower moieties of each half of the heart—that for the body in general from the left side, and that for the lungs from the right side.

Hence it follows that the great artery of the body, and the great veins of the body, are connected with opposite sides of the heart; and the great artery of the lungs and the great veins of the lungs also with opposite sides of that organ. On the other hand, the veins of the body open into the same side of the heart as the artery of the lungs, and the veins of the lungs open into the same side of the heart as the artery of the body.

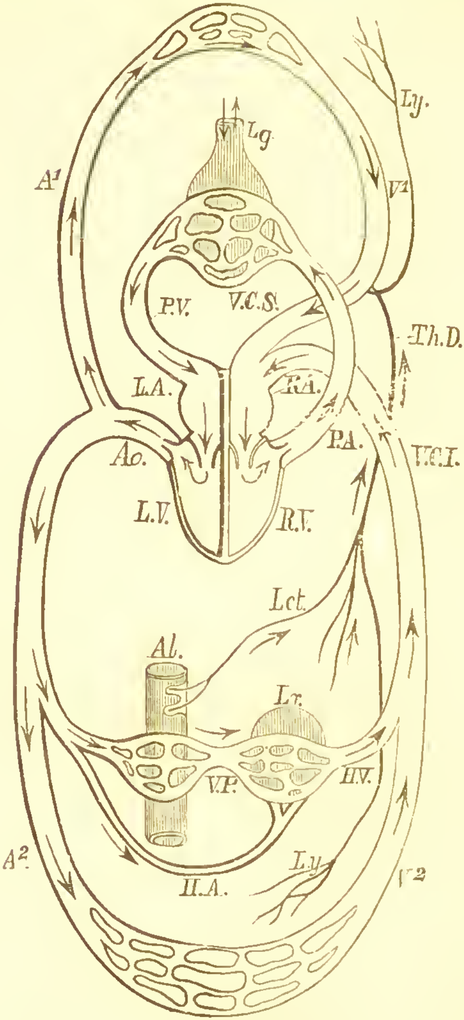

FIG. 10.—DIAGRAM OF THE HEART AND VESSELS, WITH THE COURSE OF THE CIRCULATION, VIEWED FROM BEHIND, SO THAT THE PROPER LEFT OF THE OBSERVER CORRESPONDS WITH THE LEFT SIDE OF THE HEART IN THE DIAGRAM.

L.A. left auricle; *L.V.* left ventricle; *Ao.* aorta; A^1. arteries to the upper part of the body; A^2. arteries to the lower part of the body; *H.A.* hepatic artery, which supplies the liver with part of its blood; V^1. veins of the upper part of the body; V^2. veins of the lower part of the body; *V.P.* vena portæ; *H.V.* hepatic vein; *V.C.I.* inferior vena cava; *V.C.S.* superior vena cava; *R.A.* right auricle; *R.V.* right ventricle; *P.A.* pulmonary artery; *Lg.* lung; *P.V.* pulmonary vein; *Lct.* lacteals; *Ly.* lymphatics; *Th.D.* thoracic duct; *Al.* alimentary canal; *Lr.* liver. The arrows indicate the course of the blood, lymph, and chyle. The vessels which contain arterial blood have dark contours, while those which carry venous blood have light contours.

The arteries which open into the capillaries of the substance of the heart are called *coronary arteries*, and arise, like the other arteries, from the aorta, but quite close to its origin, just beyond the semilunar valves. But the *coronary vein*, which is formed by the union of the small veins which arise from the capillaries of the heart, does not open into either of the venæ cavæ, but pours the blood which it contains directly into the division of the heart into which these cavæ open—that is to say, into the right upper division (Fig. 14).

The abdominal viscera referred to above, the veins of which do not take the usual course, are the stomach, the intestines, the spleen, and the pancreas. These veins all combine into a single trunk, which is termed the *vena portæ* (Fig. 10, *V.P.*), but this trunk does not open into the *vena cava inferior*. On the contrary, having reached the liver, it enters the substance of that organ, and breaks up into an immense multitude of capillaries, which ramify through the liver, and become connected with those into which the artery of the liver, called the *hepatic artery* (Fig. 10, *H.A.*), branches. From this common capillary mesh-work veins arise, and unite, at length, into a single trunk, the *hepatic vein* (Fig. 10, *H.V.*), which emerges from the liver, and opens into the *inferior vena cava*. The portal vein is the only great vein in the body which branches out and becomes continuous with the capillaries of an organ, like an artery.

8. The heart, to which all the vessels in the body have now been directly, or indirectly, traced, is an organ, the size of which is usually roughly estimated as equal to that of the closed fist of the person to whom it belongs, and which has a broad end turned upwards and backwards, and rather to the right side, called its *base;* and a pointed end which is called its *apex,* turned downwards and forwards, and to the left side, so as to lie opposite the interval between the fifth and sixth ribs (Fig. 12).

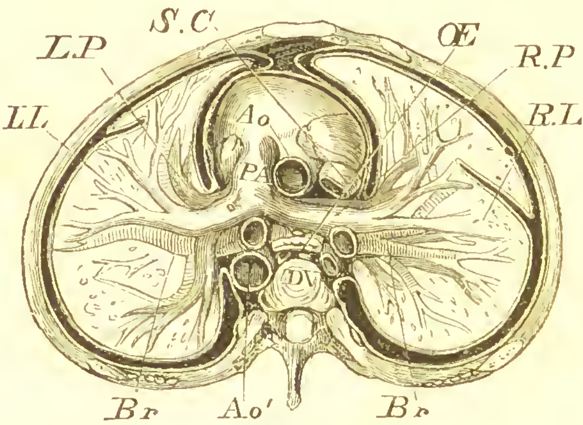

FIG. 11.—TRANSVERSE SECTION OF THE CHEST, WITH THE HEART AND LUNGS IN PLACE.

D.V. dorsal vertebra, or joint of the backbone; *Ao. Ao'.* aorta, the top of its arch being cut away in this section; *S.C.* superior vena cava; *P.A.* pulmonary artery, divided into a branch for each lung; *L.P.R.P.* left and right pulmonary veins; *Br.* Bronchi; *R.L. L.L.* right and left lungs; *Œ.* the gullet or œsophagus.

It is lodged between the lungs, nearer the front than the back wall of the chest, and is inclosed in a sort of double bag—the *pericardium*. One-half of the double bag is closely adherent to the heart itself, forming a thin coat upon its outer surface. At the base of the heart, this half of the bag passes on to the great vessels which spring from, or open into, that organ; and becomes continuous with the other half, which loosely envelopes the heart and the adherent half of the bag. Between

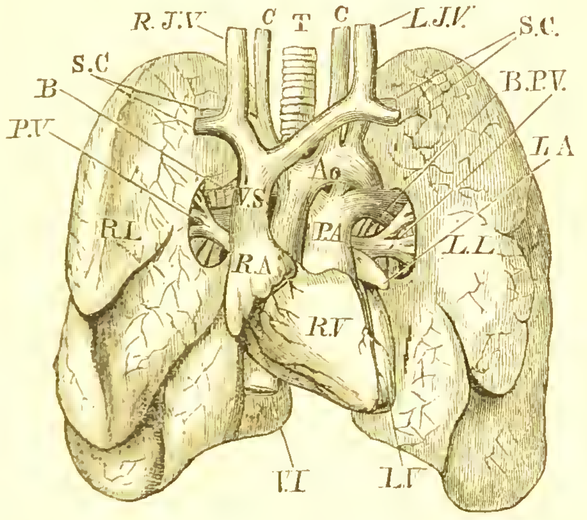

FIG. 12.—THE HEART, GREAT VESSELS, AND LUNGS. FRONT VIEW.

R.V. right ventricle; *L.V.* left ventricle; *R.A.* right auricle; *L.A.* left auricle; *Ao.* aorta; *P.A.* pulmonary artery; *P.V.* pulmonary veins; *R.L.* right lung; *L.L.* left lung; *V.S.* vena cava superior; *S.C.* subclavian vessels; *C.* carotids; *R.* and *L.J.V.* right and left jugular veins; *V.I.* vena cava inferior; *T.* trachea; *B.* bronchi.

All the great vessels but those of the lungs are cut.

the two layers of the pericardium, consequently, there is a completely closed, narrow cavity, lined by an epithelium, and secreting into its interior a small quantity of clear fluid.* The outer layer of the pericardium is firmly connected below with the upper surface of the diaphragm.

But the heart cannot be said to depend altogether upon the diaphragm for support, inasmuch as the great vessels which issue from or enter it—and for the most part pass upwards from its base—help to suspend and keep it in place.

Thus the heart is coated, outside, by one layer of the pericardium. Inside, it contains two great cavities, or "divisions," as they have been termed above, completely separated by a fixed partition which extends from the base to the apex of the heart; and, consequently, having no direct communication with one another. Each of these two great cavities is further subdivided, not longitudinally, but transversely, by a moveable partition. The cavity above the transverse partition, on each side, is called the *auricle;* the cavity below, the *ventricle*—right or left as the case may be.

Each of the four cavities has the same capacity, and is capable of containing from 4 to 6 cubic inches of water. The walls of the auricles are much thinner than those of the ventricles. The wall of the left ventricle is much thicker than that of the right ventricle; but no such difference is perceptible between the two auricles.

* This fluid, like that contained in the peritoneum, pleura, and other shut sacs of a similar character to the pericardium, is sometimes called *serum;* whence the membranes forming the walls of these sacs are frequently termed *serous membranes.*

9. In fact, as we shall see, the ventricles have more work to do than the auricles, and the left ventricle more to do than the right. Hence the ventricles have more muscular substance than the auricles, and the left ventricle than the right; and it is this excess of muscular substance which gives rise to the excess of thickness observed in the left ventricle.

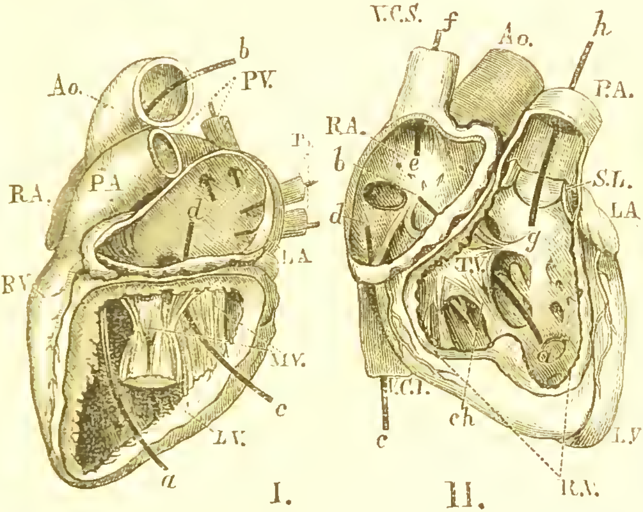

FIG. 13.—I. THE LEFT SIDE, AND II. THE RIGHT SIDE OF THE HEART DISSECTED.

I. *L.A.* the left auricle; *P.V.* the four pulmonary veins; *c d*, a style passed through the auriculo-ventricular aperture; *M.V.* the mitral valve; *a b*, a style passed through the left ventricle into the aorta; *R.A. R.V.* parts of the right side of the heart; *P.A.* pulmonary artery.

II. *R.A.* the right auricle; *V.C.S.* superior vena cava; *V.C.I.* inferior vena cava, the styles *f e*, *c d* being passed through them into the auricle; *a b*, style passed through the auriculo-ventricular aperture; *T.V.* tricuspid valve; *R.V.* right ventricle; *S.L.* semilunar valves at the base of *P.A.* the pulmonary artery, through which the style *g h* is passed; *L.A. L.V.* auricle and ventricle of the left side of the heart.

The muscular fibres of the heart are not smooth, nucleated bands, like those of the vessels, but are bundles of transversely-striped fibres, and resemble those of the chief muscles of the body, except that they have no sheath, or *sarcolemma*, such as we shall find to exist in the latter. (See Lesson XII.)

Almost the whole mass of the heart is made up of these muscular fibres, which have a very remarkable and complex arrangement. There is, however, an internal membranous and epithelial lining, called the *endocardium;* and at the junction between the auricles and ventricles, the apertures of communication between their cavities, called the *auriculo-ventricular apertures,* are strengthened by *fibrous rings.* To these rings the moveable partitions, or *valves,* between the auricles and ventricles, the arrangement of which must next be considered, are attached.

10. There are three of these partitions attached to the circumference of the right auriculo-ventricular aperture, and two to that of the left. Each is a broad, thin, but very tough and strong triangular fold of the endocardium, attached by its base, which joins on to its fellow, to the auriculo-ventricular fibrous ring; and hanging with its point downwards into the ventricular cavity. On the right side there are, therefore, three of these broad, pointed membranes, whence the whole apparatus is called the *tricuspid valve.* On the left side, there are but two, which, when detached from all their connexions but the auriculo-ventricular ring, look something like a bishop's mitre, and hence bear the name of the *mitral valve.*

The edges and apices of the valves are not completely free and loose. On the contrary, a number of fine, but strong, tendinous cords, called *chordæ tendineæ,* connect them with some column-like elevations of the fleshy substance of the walls of the ventricle, which are termed *columnæ carneæ.*

It follows, from this arrangement, that the valves oppose no obstacle to the passage of fluid from the auricles to the ventricles; but if any should be forced the other way, it will at once get between the valve and the wall of the heart, and drive the valve backwards and upwards. Partly because they soon meet in the middle and oppose one another's action, and partly because the *chordæ tendineæ* hold their edges and prevent them from going back too far, the valves, thus forced back, give rise to the formation of a complete transverse partition between the ventricle and the auricle, through which no fluid can pass.

Where the aorta opens into the left ventricle and where the pulmonary artery opens into the right ventricle, another valvular apparatus is placed, consisting in each case of three pouch-like valves, called the *semilunar valves,* which are similar to those of the veins. But as they are placed on the same level and meet in the middle line, they completely stop the passage when any fluid is forced along the artery towards the heart. On the other hand, these valves flap back and allow any fluid to pass from the heart into the artery, with the utmost readiness.

The action of the auriculo-ventricular valves may be demonstrated with great ease on a sheep's heart, in which the aorta and pulmonary artery have been tied and the greater part of the auricles cut away, by pouring water into the ventricles through the auriculo-ventricular aperture. The tricuspid and mitral valves then usually become closed by the upward pressure of the water which gets behind them. Or if the ventricles be nearly filled, the valves may be made to come together at once by gently squeezing the ventricles. In like manner, if the base of the aorta, or pulmonary artery, be cut out of the heart, so as not to injure the semilunar valves, water poured into the upper ends of the vessel will cause its valves to close tightly, and allow nothing to flow out after the first moment.

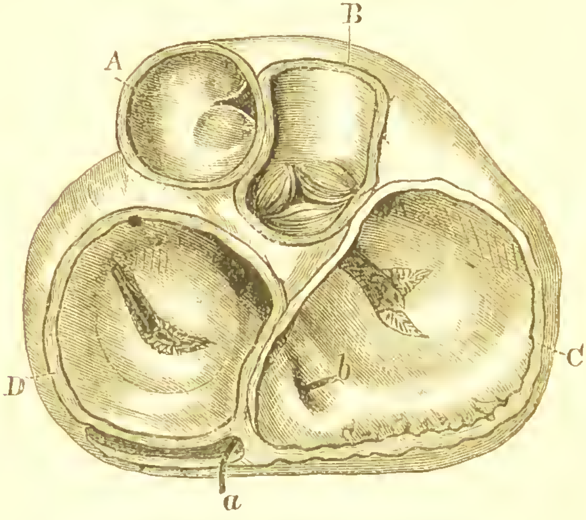

FIG. 14.—The valves of the heart displayed by cutting away both auricles and all but the bases of the pulmonary artery (*A*) and aorta (*B*); *C*, the tricuspid; *D*, the mitral valve; *a*, *b*, a style passed into the coronary vein. The semilunar valves at the origin of the aorta (*B*) are well seen, those of the pulmonary artery (*A*) being less completely displayed.

Thus the arrangement of the auriculo-ventricular valves is such, that any fluid contained in the chambers of the heart can be made to pass through the auriculo-ventricular apertures in only one direction:

that is to say, from the auricles to the ventricles. On the other hand, the arrangement of the semilunar valves is such that the fluid contents of the ventricles pass easily into the aorta and pulmonary artery, while none can be made to travel the other way from the arterial trunks to the ventricles.

11. Like all other muscular tissues, the substance of the heart is contractile; but, unlike most muscles, the heart contains within itself a something which causes its different parts to contract in a definite succession and at regular intervals.

If the heart of a living animal be removed from the body, it will go on pulsating for a longer or shorter time, much as it did while in the body. And careful attention to these pulsations will show that they consist of:—(1) A simultaneous contraction of the walls of both auricles. (2) Immediately following this, a simultaneous contraction of the walls of both ventricles. (3) Then comes a pause, or state of rest; after which the auricles and ventricles contract again in the same order as before, and their contractions are followed by the same pause as before.

If the auricular contraction be represented by A˘, the ventricular by V˘, and the pauses by —, the series of actions will be as follows: A˘ V˘ —; A˘ V˘ —; A˘ V˘ —; &c. Thus, the contraction of the heart is *rhythmical*, two short contractions of its upper and lower halves respectively, being followed by a pause of the whole, which occupies about as much time as the two contractions.

The state of contraction of the ventricle or auricle is called its *systole*—the state of relaxation, during which it undergoes dilatation, its *diastole*.

12. Having now acquired a notion of the arrange-

ment of the different pipes and reservoirs of the circulatory system, of the position of the valves, and of the rhythmical contractions of the heart, it will be easy to comprehend what must happen if, when the whole apparatus is full of blood, the first step in the pulsation of the heart occurs and the auricles contract.

By this action each auricle tends to squeeze the fluid which it contains out of itself in two directions—the one towards the great veins, the other towards the ventricles; and the direction which the blood, as a whole, will take, will depend upon the relative resistance offered to it in these two directions. Towards the great veins it is resisted by the mass of the blood contained in the veins. Towards the ventricles, on the contrary, there is no resistance worth mentioning, inasmuch as the valves are open, the walls of the ventricles, in their uncontracted state, are flaccid and easily distended, and the entire pressure of the arterial blood is taken off by the semilunar valves, which are necessarily closed.

Therefore, when the auricles contract, only a very little of the fluid which they contain will flow back into the veins, and the great proportion will pass into and distend the ventricles. As the ventricles fill and begin to resist further distension, the blood, getting behind the auriculo-ventricular valves, will push them towards one another, and almost shut them. The auricles now cease to contract, and immediately that their walls relax, fresh blood flows from the great veins and slowly distends them again.

But the moment the auricular systole is over, the ventricular systole begins. The walls of each ventricle contract vigorously, and the first effect of that contraction is to shut the auriculo-ventricular valves completely and to stop all egress towards the auricle. The pressure upon the valves becomes very considerable, and they might even be driven upwards, if it were not for the *chordæ tendineæ* which hold down their edges.

As the contraction continues and the capacities of the ventricles become diminished, the points of the wall of the heart to which the *chordæ tendineæ* are attached approach the edges of the valves; and thus there is a tendency to allow of a slackening of these cords, which, if it really took place, might permit the edges of the valves to flap back and so destroy their utility. This tendency, however, is counteracted by the *chordæ tendineæ* being connected, not directly to the walls of the heart, but to those muscular pillars, the *columnæ carneæ,* which stand out from its substance. These muscular pillars shorten at the same time as the substance of the heart contracts; and thus, just so far as the contraction of the walls of the ventricles brings the *columnæ carneæ* nearer the valves, do they, by their own contraction, pull the *chordæ tendineæ* as tight as before.

By the means which have now been described the fluid in the ventricle is debarred from passing back into the auricle; the whole force of the contraction of the ventricular walls is therefore expended in overcoming the resistance presented by the semilunar valves. This resistance has several sources, being the result, partly, of the weight of the vertical column of blood which the valves support; partly, of the reaction of the distended elastic walls of the great arteries, and partly of the friction and inertia of the blood contained in the vessels.

It now becomes obvious why the ventricles have so much more to do than the auricles, and why valves are needed between the auricles and ventricles, while none are wanted between the auricles and the veins.

All that the auricles have to do is to fill the ventricles, which offer no active resistance to that process. Hence the thinness of the walls of the auricles, and hence the needlessness of any auriculo-venous valve, the resistance on the side of the ventricle being so insignificant that it gives way, at once, before the pressure of the blood in the veins.

On the other hand, the ventricles have to overcome a great resistance in order to force fluid into elastic tubes which are already full; and if there were no auriculo-ventricular valves, the fluid in the ventricles would meet with less obstacle in pushing its way backward into the auricles and thence into the veins, than in separating the semilunar valves. Hence the necessity, firstly, of the auriculo-ventricular valves; and, secondly, of the thickness and strength of the walls of the ventricles. And since the aorta, systemic arteries, capillaries, and veins form a much larger system of tubes, containing more fluid and offering more resistance than the pulmonary arteries, capillaries, and veins, it follows that the left ventricle needs a thicker muscular wall than the right.

13. Thus, at every systole of the auricles, the ventricles are filled and the auricles emptied, the latter being slowly refilled by the pressure of the fluid in the great veins, which is amply sufficient to overcome the passive resistance of their relaxed walls. And, at every systole of the ventricles,

the arterial systems of the body and lungs receive the contents of these ventricles, and the nearly emptied ventricles remain ready to be refilled by the auricles.

We must now consider what happens in the arteries. When the contents of the ventricles are suddenly forced into these tubes (which, it must be recollected, are already full), a shock is given to the entire mass of fluid which they contain. This shock is propagated almost instantaneously throughout the fluid, becoming fainter and fainter in proportion to the increase of the mass of the blood in the capillaries, until it finally ceases to be discernible.

If the vessels were tubes of a rigid material, like gaspipes, the fluid which the arteries contain would be transported forward as far as this impulse was competent to carry it, at the same instant as the shock, throughout their whole extent. And, as the arteries open into the capillaries, the capillaries into the veins, and these into the heart, a quantity of fluid exactly equal to that driven out of the ventricles would be returned to the auricles, almost at the same moment that the ventricles contract.

However, the vessels are not rigid, but, on the contrary, very yielding tubes; and the great arteries, as we have seen, have especially elastic walls. What happens, then, when the ventricular systole takes place is—firstly, The production of the general and sudden slight shock already mentioned; and, secondly, The dilatation of the great arteries by the pressure of the increased quantity of blood forced into them.

But, when the systole is over, the force stored up in the dilated arterial walls, in the shape of elastic tension, comes into play and exerts a pressure on the fluid—the first effect of which is to shut the semilunar valves; the second, to drive the fluid from the larger arteries along the smaller ones. These it dilates in the same fashion. The fluid then passing into the capillaries, the ejection of a corresponding quantity of fluid from them into the veins, and finally from the veins into the heart, is the ultimate result of the ventricular systole.

14. Several of the practical results of the working of the heart and arteries just described now become intelligible. For example, between the fifth and sixth ribs, on the left side, a certain movement is perceptible by the finger and by the eye, which is known as the *beating* of the heart. It is the result of the striking of the apex of the heart against the pericardium and through it, on the inner wall of the chest, at this point, at the moment of the systole of the ventricles. When the systole occurs, in fact, two things happen: in the first place, as a result of the manner in which the muscular fibres of the heart are disposed, its apex bends upward sharply; and, in the second place, its front face is thrown a little downwards and forwards, in consequence of the stretching and elongation of the aorta by the blood which is thrown into it.

The result of one or other, or both of these actions combined, is the upward and forward blow of the apex of the heart which we feel.

15. Secondly, If the ear be applied over the heart certain *sounds* are heard, which recur, with great regularity, at intervals corresponding with those between every two beats. First comes a longish dull sound; then a short sharp sound; then a pause; then the long, then the sharp sound, then

another pause; and so on. There are many different opinions as to the cause of the first sound, and perhaps physiologists are not yet at the bottom of the matter; but the second sound is, without doubt, caused by the sudden closure of the semilunar valves when the ventricular systole ends. That such is the case has been proved experimentally, by hooking back the semilunar valves in a living animal, when the second sound ceases at once.

16. Thirdly, If the finger be placed upon an artery, such as that at the wrist, what is termed the *pulse* will be felt; that is to say, the elastic artery dilates somewhat, at regular intervals, which answer to the beatings of the heart. The pulse which is felt by the finger, however, does not correspond precisely with the beat of the heart, but takes place a little after it, and the interval is longer the greater the distance of the artery from the heart. The beat in the artery on the inner side of the ankle, for example, is a little later than the beat of the artery in the temple.

The reason of this is that the sense of touch by finger is only delicate enough to distinguish the dilatation of the artery by the wave of blood, which is driven along it by the elastic reaction of the aorta, and is not competent to perceive the first shock caused by the systole. But if, instead of the fingers, very delicate levers be made to rest upon any two arteries, it will be found that the pulse really begins at the same time in both, the shock of the systole making itself felt all over the vascular system at once; and that it is only the actual fluid, which is propelled into the two arteries by the elastic reaction of the greater vessels, which takes longer to reach and distend the more distant branch.

17. Fourthly, When an artery is cut, the outflow of the fluid which it contains is increased by *jerks*, the intervals of which correspond with the intervals of the beats of the heart. The cause of this is plainly the same as that of the pulse; the force which would be employed in distending the walls of the artery, were the latter entire, is spent in jerking the fluid out when the artery is cut.

18. Fifthly, Under ordinary circumstances, the pulse is no longer to be detected in the capillaries, or in the veins. This arises from several circumstances. One of them is that the capacity of the branches of an artery is greater than the capacity of its trunk, and the capacity of the capillaries, as a whole, is greater than that of all the small arteries put together. Hence, supposing the capacity of the trunk to be 10, that of its branches 50, and that of the capillaries into which these open 100, it is clear that a quantity of fluid thrown into the trunk, sufficient to dilate it by one-tenth, and to produce a very considerable and obvious effect, could not distend each branch by more than $\frac{1}{50}$th, and each capillary by $\frac{1}{100}$th of its volume, an effect which might be quite imperceptible.

19. Again, the flow of the fluid is retarded by the subdivision of the tubes which contain it; and the multitude of minute impulses into which the primary blow of the systole is subdivided in the small vessels, become lost among these obstacles and fused into one general and steady pressure. This loss of the distinct effect of the heart's action may be likened to the result of pumping into a horse-trough. Where the water flows into the trough, the splashes and waves, caused by the intermitting fall of water from the pump, are very obvious; but

the water will flow steadily and evenly from a tap, open at the other end of the trough.

20. Finally, in consequence of the resistance to its passage, resulting from the extremely minute size and subdivision of the capillaries, the fluid, to a certain extent, accumulates in the arteries, and keeps their walls in a constant state of distension, which is maintained by each successive beat of the heart. In other words, one beat follows another before the effect of the first has ceased.

As the effect of each systole becomes diminished in the smaller vessels by the causes above mentioned, that of this constant pressure becomes more obvious, and gives rise to a steady passage of the fluid from the arteries towards the veins. In this way, in fact, the arteries perform the same functions as the air-reservoir of a fire-engine, which converts the jerking impulse given by the pumps into the steady flow of the delivery hose.

Such is the general result of the mechanical conditions of the organs of the circulation combined with the rhythmical activity of the heart. This activity drives the fluid contained in these organs out of the heart into the arteries, thence to the capillaries, and from them through the veins back to the heart. And in the course of these operations it gives rise, incidentally, to the beating of the heart, the sounds of the heart, and the pulse.

21. It is now necessary to trace the exact course of the circulation as a whole. And we may conveniently commence with the portion of the blood contained at any moment in the right auricle. The contraction of the right auricle drives that fluid into the right ventricle; the ventricle then contracts and forces it into the pulmonary artery;

from hence it passes into the capillaries of the lungs. Leaving these, it returns by the four pulmonary veins to the left auricle; and the contraction of the left auricle drives it into the left ventricle.

The systole of the left ventricle forces the blood into the aorta. The branches of the aorta convey it into all parts of the body except the lungs; and from the capillaries of all these parts, except from those of the intestines and certain other viscera in the abdomen, it is conveyed, by vessels which gradually unite into larger and larger trunks, into either the superior or the inferior *vena cava*, which carry it to the right auricle once more.

But the blood brought to the capillaries of the stomach and intestines, spleen and pancreas, is gathered into veins which unite into a single trunk —the *vena portæ*. The vena portæ distributes its blood to the liver, mingling with that supplied to the capillaries of the same organ by the hepatic artery. From these capillaries it is conveyed by small veins, which unite into a large trunk—the *hepatic vein*, which opens into the inferior vena cava. The flow of the blood from the abdominal viscera, through the liver, to the hepatic vein is called the *portal circulation*.

The heart itself is supplied with blood by the two *coronary arteries* which spring from the root of the aorta just above two of the semilunar valves. The blood from the capillaries of the heart is carried back by the coronary vein, not to either vena cava, but to the right auricle. The opening of the coronary vein is protected by a valve, so as to prevent the right auricle from driving the venous blood which it contains back into the vessels of the heart.

22. Thus, the *shortest possible course* which any

particle of the blood can take in order to pass from one side of the heart to the other, is to leave the aorta by one of the coronary arteries, and return to the right auricle by the coronary vein. And in order to pass through the *greatest possible number of capillaries* and return to the point from which it started, a particle of blood must leave the heart by the aorta and traverse the arteries which supply the alimentary canal, spleen, and pancreas. It then enters, 1stly, the capillaries of these organs; 2dly, the capillaries of the liver; and, 3dly, after passing through the right side of the heart, the capillaries of the lungs, from which it returns to the left side and eventually to the aorta.

Furthermore, from what has been said respecting the lymphatic system, it follows that any particle of matter which enters a lacteal of the intestine, will reach the right auricle by the superior cava, after passing through the lymph capillaries and channels of sundry lymphatic glands; while anything which enters the adjacent blood capillary in the wall of the intestine will reach the right auricle by the inferior cava, after passing through the blood capillaries of the liver.

23. It has been shown above (§ 2) that the small arteries and veins may be directly affected by the nervous system, which controls the state of contraction of their muscular walls, and so regulates their calibre. The effect of this power of the nervous system is to give it a certain control over the circulation in particular spots, and to produce such a state of affairs that, although the force of the heart and the general condition of the vessels remain the same, the state of the circulation may be very different in different localities.

Blushing is a purely local modification of the circulation of this kind, and it will be instructive to consider how a blush is brought about. An emotion—sometimes pleasurable, sometimes painful—takes possession of the mind: thereupon a hot flush is felt, the skin grows red, and according to the intensity of the emotion these changes are confined to the cheeks only, or extend to the "roots of the hair," or "all over."

What is the cause of these changes? The blood is a red and a hot fluid; the skin reddens and grows hot, because its vessels contain an increased quantity of this red and hot fluid; and its vessels contain more, because the small arteries suddenly dilate, the natural moderate contraction of their muscles being superseded by a state of relaxation. In other words, the action of the nerves which cause this muscular contraction is suspended.

On the other hand, in many people, extreme terror causes the skin to grow cold, and the face to appear pale and pinched. Under these circumstances, in fact, the supply of blood to the skin is greatly diminished, in consequence of an excessive stimulation of the nerves of the small arteries, which causes them to contract and so to cut off the supply of blood more or less completely.

24. That this is the real state of the case may be proved experimentally upon rabbits. These animals, it is true, do not blush naturally, but they may be made to blush artificially. If, in a rabbit, the sympathetic nerve which sends branches to the vessels of the head is cut, the ear of the rabbit, which is covered by so delicate an integument that the changes in its vessels can be readily perceived, at once blushes. That is to say, the vessels dilate,

fill with blood, and the ear becomes red and hot, The reason of this is, that when the sympathetic is cut, the nervous stimulus which is ordinarily sent along its branches is interrupted, and the muscles of the small vessels, which were slightly contracted, become altogether relaxed.

And now it is quite possible to produce pallor and cold in the rabbit's ear. To do this it is only necessary to irritate the cut end of the sympathetic which remains connected with the vessels. The nerve then becomes excited, so that the muscular fibres of the vessels are thrown into a violent state of contraction, which diminishes their calibre so much that the blood can hardly make its way through them. Consequently, the ear becomes pale and cold.

25. The practical importance of this local control exerted by the nervous system is immense. When exposure to cold gives a man catarrh, or inflammation of the lungs, or diarrhœa, or some still more serious affection of the abdominal viscera, the disease is brought about through the nervous system. The impression made by the cold on the skin is conveyed to the nervous centres, and so influences the *vaso-motor nerves* (as the nerves which govern the walls of the vessels are called) of the organ affected as to cause their partial paralysis, and produce that state of *congestion* (or undue distension of the vessels) which so commonly ends in inflammation. (See Lesson XI. § 15.)

26. Is the heart, in like manner, under the control of the central nervous system?

As we all know, it is not under the direct influence of the will, but every one is no less familiar with the fact that the actions of the heart are wonderfully affected by all forms of emotion. Men and women often faint, and have sometimes been killed by sudden and violent joy or sorrow; and when they faint or die in this way, they do so because the perturbation of the brain gives rise to a something which arrests the heart as dead as you stop a stop-watch with a spring. On the other hand, other emotions cause that extreme rapidity and violence of action which we call palpitation.

Now there are three sets of nerves in the heart: one set are supplied by *ganglia,* or masses of nerve-cells, in its substance; another set come from the *sympathetic* nerve; a third set are branches of a remarkable nerve, which proceeds straight from the brain, and is called the *pneumogastric* nerve. There is every reason to believe that the regular rhythmical succession of the ordinary contractions of the heart depends upon the ganglia lodged in its substance. At any rate, it is certain that these movements depend neither on the sympathetic, nor on the pneumogastric, since they go on as well when the heart is removed from the body.

In the next place, there is much reason to believe that the influence which increases the rapidity of the heart's action is exerted through the sympathetic.

And lastly, it is quite certain that the influence which arrests the heart's action is supplied by the pneumogastric. This may be demonstrated in animals, such as frogs, with great ease.

27. If a frog be pithed, or its brain destroyed, so as to obliterate all sensibility, the animal will continue to live, and its circulation will go on perfectly well for an indefinite period. The body may be laid open without causing pain or other disturbance, and then the heart will be observed beating with great regu-

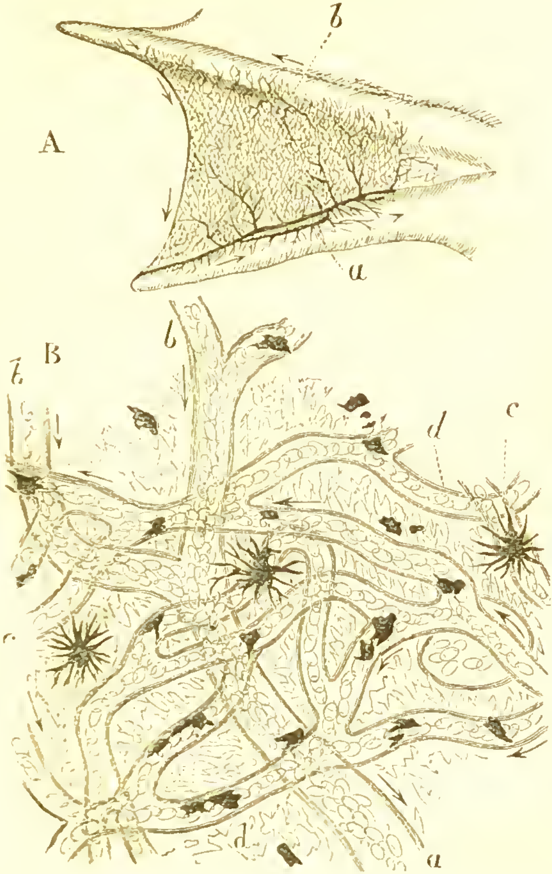

FIG. 15.

A. Two toes of a frog's foot, with the intervening web, slightly enlarged: *a*, veins; *b*, arteries, connected by a network of capillaries.

B. A small portion of the network magnified about 100 diameters: *a b* are small veins, and *d* capillaries, all full of large oval blood-corpuscles, moving in the direction indicated by the arrows; *c*, star-shaped, coloured patches or pigment cells in the frog's skin.

larity. It is possible to make the heart move a long index backwards and forwards, like the inverted pendulum which musicians term a metronome; and if frog and index are covered with a glass shade, the air under which is kept moist, the index will vibrate with great steadiness for a couple of days.

It is easy to adjust to the frog thus prepared a contrivance by which electrical shocks may be sent through the pneumogastric nerves, so as to irritate them. The moment this is done the index stops dead, and the heart will be found quiescent, with relaxed and distended walls. After a little time the influence of the pneumogastric passes off, the heart recommences its work as vigorously as before, and the index vibrates through the same arc as formerly. With careful management, this experiment may be repeated very many times; and after every arrest by the irritation of the pneumogastric, the heart resumes its work.

28. The evidence that the blood circulates in man, although perfectly conclusive, is almost all indirect. But certain of the lower animals, the whole, or parts, of the body of which are transparent, readily afford direct proof of the circulation, the blood visibly rushing from the arteries into the capillaries, and from the capillaries into the veins, so long as the animal is alive and its heart is at work. The animal in which the circulation can be most conveniently observed is the frog. The web between its toes is very transparent, and the particles suspended in its blood are so large that they can be readily seen as they slip swiftly along with the stream of blood, when the toes are fastened out, and the intervening web is examined under even a low magnifying power (Fig. 15).

LESSON III.

THE BLOOD AND THE LYMPH.

1. In order to become properly acquainted with the characters of the blood it is necessary to examine it with a microscope magnifying at least three or four hundred diameters. Provided with this instrument, a hand lens, and some slips of thick and thin glass, the student will be enabled to follow the present Lesson.

The most convenient mode of obtaining small quantities of blood for examination is to twist a piece of string, pretty tightly, round the middle of the last joint of the middle, or ring finger, of the left hand. The end of the finger will immediately swell a little, and become darker coloured, in consequence of the obstruction to the return of the blood in the veins caused by the ligature. When in this condition, if it be slightly pricked with a sharp clean needle (an operation which causes hardly any pain), a good-sized drop of blood will at once exude. Let it be deposited on one of the slips of thick glass, and covered lightly and gently with a piece of the thin glass, so as to spread it out evenly into a thin layer. Let a second slide receive another drop, and let it be put under an inverted tumbler so as to keep it from drying. Let a third drop be dealt with in the same way, a few granules of common salt being first added to the drop.

2. To the naked eye the layer of blood upon the first slide will appear of a pale reddish colour, and quite clear and homogeneous. But on viewing it

with even a pocket lens its apparent homogeneity will disappear, and it will look like a mixture of excessively fine yellowish-red particles, like sand, or dust, with a watery, almost colourless, fluid. Immediately after the blood is drawn the particles will appear to be scattered very evenly through the fluid, but by degrees they aggregate into minute patches, and the layer of blood becomes more or less spotty.

The "particles" are what are termed the *corpuscles* of the blood; the nearly colourless fluid in which they are suspended is the *plasma.*

The second slide may now be examined. The drop of blood will be unaltered in form, and may perhaps seem to have undergone no change. But if the slide be inclined, it will be found that the drop no longer flows; and, indeed, the slide may be inverted without the disturbance of the drop, which has become solidified, and may be removed, with the point of a penknife, as a hemispherical gelatinous mass. The mass is quite soft and moist, so that this setting, or *coagulation*, of a drop of blood is something very different from its drying.

On the third slide, this process of coagulation will be found not to have taken place, the blood remaining as fluid as it was when it left the body. The salt, therefore, has prevented the coagulation of the blood. Thus this very simple investigation teaches that blood is composed of a nearly colourless plasma, in which many coloured corpuscles are suspended; that it has a remarkable power of coagulating; and that this coagulation may be prevented by artificial means, such as the addition of salt.

3. If, instead of using the hand lens, the drop of blood on the first slide be placed under the

microscope, the particles, or corpuscles, of the blood will be found to be bodies with very definite characters, and of two kinds, called respectively the *red corpuscles* and the *colourless corpuscles*. The former are much more numerous than the latter, and have a yellowish-red tinge; while the latter, somewhat larger than the red corpuscles, are, as their name implies, pale and devoid of coloration.

4. The corpuscles differ also in other and more important respects. The *red corpuscles* are flattened circular disks, on an average $\frac{1}{3200}$th of an inch in diameter, and having about one-fourth of that thickness. It follows that rather more than 10,000,000 of them will lie on a space one inch square, and that the volume of each corpuscle does not exceed $\frac{1}{120,000,000,000}$th of a cubic inch.

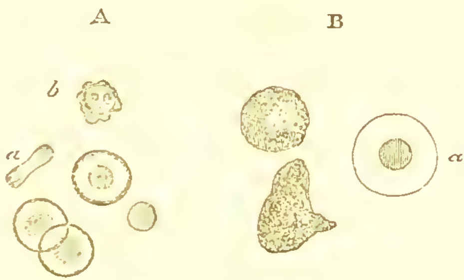

FIG. 16.—CORPUSCLES OF HUMAN BLOOD,

Magnified about 600 diameters.

A. Red Corpuscles: *a*, a corpuscle seen edgeways; *b*, a corpuscle in an altered state, arising from pressure. A small spheroidal red corpuscle, such as may be frequently met with in the blood, is represented beside the larger discoidal ones.

B. Colourless Corpuscles: *a*, a colourless corpuscle acted upon by diluted acetic acid, showing its nucleus.

The broad faces of the disks are not flat, but somewhat concave, as if they were pushed in towards one another. Hence the corpuscle is thinner in the middle than at the edges, and when viewed under the microscope, by transmitted light, looks clear in the middle and darker at the edges, or dark in the middle and clear at the edges, according to circumstances. When, on the other hand, the disks roll over and present their edges to the eye, they look like rods. All these varieties of appearance may be made intelligible by turning a round biscuit or muffin, bodies similar in shape to the red corpuscles, in various ways before the eye.

The red corpuscles are very soft, flexible, and elastic bodies, so that they readily squeeze through apertures and passages narrower than their own diameters, and immediately resume their proper shapes. The exterior of each corpuscle is denser than its interior, which contains a semi-fluid, or quite fluid matter, of a red colour, called *hæmoglobin*. By proper processes this may be resolved into an albuminous substance termed *globulin*, and a peculiar colouring matter, which is called *hæmatin*. The interior substance presents no distinct structure.

From the density of the outer as compared with the inner substance of each corpuscle, they are, practically, small flattened bags, or sacs, the form of which may be changed by altering the density of the plasma. Thus, if it be made denser by dissolving saline substances, or sugar, in it, water is drawn from the contents of the corpuscle to the dense plasma, and the corpuscle becomes still more flattened. On the other hand, if the plasma be diluted with water, the latter forces itself into and dilutes the contents of the corpuscle, causing the latter to swell out, and even become spherical; and, by adding dense and weak solutions alternately, the corpuscles may be made to become successively spheroidal and discoidal. Exposure to carbonic acid gas seems to cause the corpuscles to swell out; oxygen gas, on the contrary, appears to flatten them.

FIG. 17.—SUCCESSIVE FORMS ASSUMED BY COLOURLESS CORPUSCLES OF HUMAN BLOOD

Magnified about 600 diameters.

The interval between the forms *a b c d* was a minute; between *d* and *e* two minutes; so that the whole series of changes from *a* to *e* took five minutes.

5. The *colourless corpuscles* are larger than the red corpuscles, their average diameter being $\frac{1}{2500}$th of an inch. They are further seen, at a glance, to differ from the red corpuscles by the extreme irregularity of their form, and by their tendency to attach themselves to the glass slide, while the red corpuscles float about and tumble freely over one another.

A still more remarkable feature of the colourless corpuscles than the irregularity of their form is the unceasing variation of shape which they exhibit. The form of a red corpuscle is changed only by influences from without, such as pressure, or the like; that of the colourless corpuscle is undergoing constant alteration, as the result of changes taking place in its own substance. To see these changes well, a microscope with a magnifying power of five or six hundred diameters is requisite; and, even then, they are so gradual, that the best way to ascertain their existence is to make a drawing of a given colourless corpuscle at intervals of a minute or two. This is what has been done with the corpuscle represented in Fig. 17, in which *a* represents the form of the corpuscle when first observed; *b*, its form a minute afterwards; *c*, that at the end of the second; *d*, that at the end of the third; and *e*, that at the end of the fifth minute.

Careful watching of a colourless corpuscle, in fact, shows that every part of its surface is constantly changing—undergoing active contraction, or being passively dilated by the contraction of other parts. It exhibits contractility in its lowest and most primitive form.

6. While they are thus living and active, no correct notion can be formed of the structure of the colourless corpuscles. By diluting the blood with water, or, still better, with water acidulated with acetic acid, the corpuscles are killed, and become distended, so that their real nature is shown. They are then seen to be spheroidal bags, or sacs, with very thin walls; and to contain in their interior a fluid which is either clear or granular, together with a spheroidal vesicular body, which is called the *nucleus* (Fig. 16, B, *a*). It sometimes, though very rarely, happens that the nucleus has a red tint.

The sac-like colourless corpuscle, with its nucleus, is what is called a *nucleated cell*. It will be observed that it lives in a free state, in the plasma of the blood, and that it exhibits an independent contractility. In fact, except that it is dependent for the conditions of its existence upon the plasma, it might be compared to one of those simple organisms which are met with in stagnant water, and are called *Amœbæ*.

7. That the red corpuscles are in some way or other derived from the colourless corpuscles may be regarded as certain; but the steps of the process have not been made out with perfect certainty. There is very great reason, however, for believing that the red corpuscle is simply the nucleus of the colourless corpuscle somewhat enlarged; flattened from side to side; changed, by development within its interior of a red colouring matter; and set free by the bursting of the sac or wall of the colourless corpuscle. In other words, the red corpuscle is a free nucleus.

The origin of the colourless corpuscles themselves is not certainly determined; but it is highly probable that they are constituent cells of certain parts of the solid substance of the body which have been detached and carried into the blood, and that this process is chiefly effected in what are called the *ductless glands* (Lesson V. § 27), from whence the detached cells pass, as *lymph-corpuscles*, directly or indirectly, into the blood.

The following facts are of importance in their bearing on the relation between the different kinds of corpuscles:—

(*a*) The invertebrate animals,* which have true blood-corpuscles, possess only such as resemble the colourless corpuscles of man.

(*b*) The lowest vertebrate animal, the Lancelet (*Amphioxus*), possesses only colourless corpuscles;

* Invertebrate animals are animals devoid of backbones, such as insects, snails, sea-anemones, &c. Vertebrate animals are fishes, amphibia, reptiles, birds, and mammals.

and the very young embryos * of all vertebrate animals have only colourless and nucleated corpuscles.

(*c*) All the vertebrated animals, the young of which are born from eggs,† have two kinds of corpuscles—colourless corpuscles, like those of man, and large red-coloured corpuscles, which are generally oval, and further differ from those of man in presenting a nucleus. In fact, they are simply the colourless corpuscles enlarged and coloured.

(*d*) All animals which suckle their young (or what are called mammals) have, like man, two kinds of corpuscles: colourless ones, and small coloured corpuscles—the latter being always flattened, and devoid of any nucleus. They are usually circular, but in the camel tribe they are elliptical. And it is worthy of remark that, in these animals, the nuclei of the colourless corpuscles become elliptical.

(*e*) The colourless corpuscles differ much less from one another in size and form, in the vertebrate series, than the coloured. The latter are smallest in the little Musk Deer, in which animal they are about a quarter as large as those of man. On the other hand, the red corpuscles are largest in the *Amphibia* (or Frogs and Salamanders), in some of which animals they are ten times as long as in man.

8. As the blood dies, its several constituents, which have now been described, undergo marked changes.

The *colourless corpuscles* lose their contractility, but otherwise undergo little alteration. They tend to cohere neither with one another, nor with the red

* An embryo is the rudimentary unborn young of any creature.

† These are fishes, amphibia, reptiles, and birds.

corpuscles, but adhere to the glass plate on which they are placed.

It is quite otherwise with the *red corpuscles*, which at first, as has been said, float about and roll, or slide, over each other quite freely. After a short time (the length of which varies in different persons, but usually amounts to two or three minutes), they seem, as it were, to become sticky, and tend to cohere; and this tendency increases until, at length, the great majority of them become applied face to face, so as to form long series, like rolls of coin. The end of one roll cohering with the sides of another, a network of various degrees of closeness is produced.

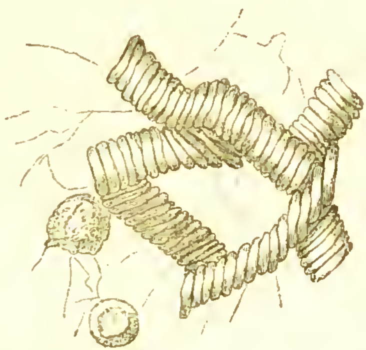

FIG. 18.—RED CORPUSCLES OF HUMAN BLOOD ARRANGED IN COHERENT ROLLS.

Magnified about 600 diameters.

One free red corpuscle and one colourless corpuscle are seen, and the plasma in the field of view is traversed by very delicate filaments of fibrine.

The corpuscles remain thus coherent for a certain length of time, but eventually separate and float freely again. The addition of a little water, or dilute acids, or saline solutions, will at once cause the rolls to break up.

It is from this running of the corpuscles together into patches of network that the change noted above in the appearances of the layer of blood, viewed with a lens, arises. So long as the corpuscles are separate, the sandy appearance lasts; but when they run together, the layer appears patchy or spotted.

The red corpuscles rarely, if ever, all run together into rolls, some always remaining free in the meshes of the net. In contact with air, or if subjected to pressure, many of the red corpuscles become covered with little knobs, so as to look like minute mulberries—an appearance which has been mistaken for a breaking up, or spontaneous division, of the corpuscles (Fig. 16, A, *b*).

9. There is a still more remarkable change which the red blood-corpuscles occasionally undergo. Under certain circumstances, the peculiar red substance which forms the chief mass of their contents, and which has been called *hæmoglobin* (from its readily breaking up into globulin and hæmatin, § 6), separates in a crystalline form. In man, these crystals have the shape of prisms; in other animals they take other forms. Treatment of the blood with oxygen and with carbonic acid in sunlight greatly facilitates this process, so that the easiest way to see these *blood crystals* is to expose a drop of blood to the air, then moisten it with water, and then, by breathing several times on it, supply it with carbonic acid. The colour of the drop brightens as the crystals form in it.

10. When the layer of blood has been drawn ten or fifteen minutes, the plasma will be seen to be no longer clear. It then exhibits multitudes of

extremely delicate filaments of a substance called *Fibrin,* which have been deposited from it, and which traverse it in all directions, uniting with one another and with the corpuscles, and binding the whole into a semi-solid mass.

It is this deposition of fibrin which is the cause of the apparent solidification, or coagulation, of the drop upon the second slide; but the phenomena of coagulation, which are of very great importance, cannot be properly understood until the behaviour of the blood, when drawn in larger quantity than a drop, has been studied.

11. When, by the ordinary process of opening a vein with a lancet, a quantity of blood is collected into a basin, it is at first perfectly fluid; but in a quarter of an hour, and sometimes in less than half that time, it separates into two very different constituents—the one a clear, yellowish, liquid, the other a red, semi-solid mass, which lies in the liquid, and at the surface is paler in colour and firmer than in its deeper part.

The liquid is called the *serum;* the semi-solid mass the clot, or *crassamentum.* Now the clot obviously contains the corpuscles of the blood, bound together by some other substance; and this last, if a small part of the clot be examined microscopically, will be found to be that fibrous-looking matter, *fibrin,* which has been seen forming in the thin layer of blood. Thus the clot is equivalent to the corpuscles *plus* the fibrin of the plasma, while the serum is the plasma *minus* the fibrinous elements which it contained.

12. The corpuscles of the blood are slightly heavier than the plasma, and therefore, when the blood is drawn, they sink very slowly towards the bottom.

Hence the upper part of the clot contains fewer corpuscles, and is lighter in colour, than the lower part—there being fewer corpuscles left in the upper layer of plasma for the fibrin to catch when it sets. And there are some conditions of the blood in which the corpuscles run together much more rapidly and in denser masses than usual. Hence they more readily overcome the resistance of the plasma to their falling, just as feathers stuck together in masses fall much more rapidly through the air than the same feathers when loose. When this is the case, the upper stratum of plasma is quite free from red corpuscles before the fibrin forms in it; and, consequently, the uppermost layer of the clot is nearly white: it receives the name of the *buffy coat.*

After the clot is formed, the fibrin shrinks and squeezes out much of the serum contained within its meshes; and, other things being equal, it contracts the more the fewer corpuscles there are in the way of its shrinking. Hence, when the buffy coat is formed, it usually contracts so much as to give the clot a cup-like upper surface.

Thus the buffy coat is fibrin naturally separated from the red corpuscles; the same separation may be effected, artificially, by whipping the blood with twigs as soon as it is drawn, until its coagulation is complete. Under these circumstances the fibrin will collect upon the twigs, and a red fluid will be left behind, consisting of the serum *plus* the red corpuscles, and many of the colourless ones.

13. The coagulation of the blood is hastened, retarded, or temporarily prevented by many circumstances.

(*a*) *Temperature.*—A high temperature accelerates the coagulation of the blood; a low one retards it very greatly; and some experimenters have stated that, when kept at a sufficiently low temperature, it does not coagulate at all.

(*b*) *The addition of soluble matter to the blood.*—Many saline substances, and more especially sulphate of soda and common salt, dissolved in the blood in sufficient quantity, prevent its coagulation; but coagulation sets in when water is added, so as to dilute the saline solution.

(*c*) *Contact with living or not-living matter.*—Contact with not-living matter promotes the coagulation of the blood. Thus, blood drawn into a basin begins to coagulate first where it is in contact with the sides of the basin; and a wire introduced into a living vein will become coated with fibrin, although perfectly fluid blood surrounds it.

On the other hand, direct contact with living matter retards, or altogether prevents, the coagulation of the blood. Thus blood remains fluid for a very long time in a portion of a vein which is tied at each end.

The heart of a turtle remains alive for a lengthened period (many hours or even days) after it is extracted from the body; and, so long as it remains alive, the blood contained in it will not coagulate, though, if a portion of the same blood be removed from the heart it will coagulate in a few minutes.

Blood taken from the body of the turtle, and kept from coagulating by cold for some time, may be poured into the separated, but still living, heart, and then will not coagulate.

Freshly deposited fibrin acts somewhat like living matter, coagulable blood remaining fluid for a long time in tubes coated with such fibrin.

14. The coagulation of the blood is an altogether

physico-chemical process, dependent upon the properties of certain of the constituents of the plasma, apart from the vitality of that fluid. This is proved by the fact that if blood-plasma be prevented from coagulating by cold, and greatly diluted, a current of carbonic acid passed through it will throw down a white powdery substance. If this white substance be dissolved in a weak solution of common salt, or in an extremely weak solution of potash or soda, it, after a while, coagulates, and yields a clot of true pure fibrin. It would be absurd to suppose that a substance which has been precipitated from its solution, and redissolved, still remains alive.

There are reasons for believing that this white substance consists of two constituents of very similar composition, which exist separately in living blood, and the union of which is the cause of the act of coagulation. These reasons may be briefly stated thus:—The pericardium and other serous cavities in the body contain a clear fluid, which has exuded from the blood-vessels, and contains the elements of the blood without the blood-corpuscles. This fluid sometimes coagulates spontaneously, as the blood-plasma would do, but very often shows no disposition to spontaneous coagulation. When this is the case, it may nevertheless be made to coagulate, and yield a true fibrinous clot, by adding to it a little serum of blood.

Now, if serum of blood be largely diluted with water and a current of carbonic acid gas passed through it, a white powdery substance will be thrown down; this, redissolved in a dilute saline, or extremely dilute alkaline, solution will, when added to the pericardial fluid, produce even as good a clot as that obtained with the original serum.

This white substance has been called *globulin*. It exists not only in serum, but also, though in smaller quantities, in connective tissue, in the cornea, in the humours of the eye, and in some other fluids of the body.

It possesses the same general chemical properties as the albuminous substance which enters so largely into the composition of the red corpuscles (§ 4), and hence, at present, bears the same name. But when treated with chemical reagents, even with such as do not produce any appreciable effect on its chemical composition, it very speedily loses its peculiar power of causing serous fluids to coagulate. For instance, this power is destroyed by an excess of alkali, or by the presence of acids.

Hence, though there is great reason to believe that the *fibrino-plastic globulin* (as it has been called) which exists in serum does really come from the red corpuscles, the globulin which is obtained in large quantities from these bodies, by the use of powerful reagents, has no coagulating effect at all on pericardial or other serous fluids.

Though globulin is so susceptible of change when in solution, it may be dried at a low temperature and kept in the form of powder, for many months without losing its coagulating power.

Thus *globulin*, added, under proper conditions, to serous effusion, is a coagulator of that effusion, giving rise to the development of fibrin in it.

It does so by its interaction with a substance contained in the serous effusion, which can be extracted by itself, and then plays just the same part towards a solution of globulin, as globulin does towards its solution. This substance has been called *fibrinogen*. It is exceedingly like globulin, and may be thrown down from serous exudation by carbonic acid, just as globulin may be precipitated from the serum of the blood. When redissolved in an alkaline solution, and added to any fluid containing globulin, it acts as a coagulator of that fluid, and gives rise to the development of a clot of fibrin in it. In accordance with what has just been stated, serum of blood which has completely coagulated may be kept in one vessel, and pericardial fluid in another, for an indefinite period, if spontaneous decomposition be prevented, without the coagulation of either. But let them be mixed, and coagulation sets in.

Thus it seems to be clear, that the coagulation of the blood, and the formation of fibrin, are caused primarily by the interaction of two substances (or two modifications of the same substance), *globulin* and *fibrinogen*, the former of which exists in the serum of the blood, and in some tissues of the body; while the latter is known, at present, only in the plasma of the blood, of the lymph, and of the chyle, and in fluids derived from them.

15. The proverb that "blood is thicker than water" is literally true, as the blood is not only "thickened" by the corpuscles, of which it has been calculated that no fewer than 70,000,000,000 (eighty times the number of the human population of the globe) are contained in a cubic inch, but is rendered slightly viscid by the solid matters dissolved in the plasma. The blood is thus rendered heavier than water, its specific gravity being about 1055. In other words, twenty cubic inches of blood have about the same weight as twenty-one cubic inches of water.

The corpuscles are heavier than the plasma, and their volume is usually somewhat less than that of the plasma. Of colourless corpuscles there are usually not more than three or four for every thousand of red corpuscles; but the number varies very much, increasing shortly after food is taken, and diminishing in the intervals between meals.

The blood is hot, its temperature being about 100° Fahrenheit.

16. Considered chemically, the blood is an alkaline fluid, consisting of water, of solid and of gaseous matters.

The proportions of these several constituents vary according to age, sex, and condition, but the following statement holds good on the average:—

In every 100 parts of blood there are 79 parts of water and 21 parts of dry solids; in other words, the water and the solids of the blood stand to one another in about the same proportion as the nitrogen and the oxygen of the air. Roughly speaking, one quarter of the blood is dry, solid matter; three quarters water. Of the 21 parts of dry solids, 12 ($=\frac{4}{7}$ths) belong to the corpuscles. The remaining 9 are about two-thirds (6·7 parts $=\frac{2}{7}$ths) albumen (a substance like white of egg, coagulating by heat), and one third ($=\frac{1}{7}$th of the whole solid matter) a mixture of saline, fatty, and saccharine matters, sundry products of the waste of the body, and fibrin. The quantity of the latter constituent is remarkably small in relation to the conspicuous part it plays in the act of coagulation. Healthy blood, in fact, yields, in coagulating, not more than from two to four parts in a thousand of its weight of fibrin.

The total quantity of gaseous matter contained in the blood is equal to rather less than half the *volume* of the blood; that is to say, 100 cubic inches of blood will contain rather less than 50 cubic inches of gases. These gaseous matters are carbonic acid, oxygen, and nitrogen; or, in other words, the same gases as those which exist in the atmosphere, but in totally different proportions; for whereas air contains nearly three-fourths nitrogen, one-fourth oxygen, and a mere trace of carbonic acid, the average composition of the blood gases is nearly two-thirds carbonic acid, rather less than one-third oxygen, and not one-tenth nitrogen.

It is important to observe that blood contains much more oxygen gas than could be held in solution by pure water at the same temperature and pressure. This power of holding oxygen appears in some way to depend upon the corpuscles, firstly, because mere serum has no greater power of absorbing oxygen than pure water has; and secondly, because a solution of hæmoglobin absorbs oxygen very readily. It is further to be remarked, that some substances which are capable of being oxidated with great readiness—such as pyrogallic acid—are not affected by their passage through the blood. Thus it would appear that the oxygen is not quite free, but is held in some sort of loose chemical combination with a constituent of the blood contained in the corpuscles.

The corpuscles differ chemically from the plasma, in containing a large proportion of the fats and phosphates, all the iron, and almost all the potash, of the blood; while the plasma, on the other hand, contains by far the greater part of the chlorine and the soda.

17. The blood of adults contains a larger proportion of solid constituents than that of children, and that of men more than that of women; but the difference

of sex is hardly at all exhibited by persons of flabby, or what is called lymphatic, constitution.

Animal diet tends to increase the quantity of the red corpuscles; a vegetable diet and abstinence to diminish them. Bleeding exercises the same influence in a still more marked degree, the quantity of red corpuscles being diminished thereby in a much greater proportion than that of the other solid constituents of the blood.

18. The total quantity of blood contained in the body varies at different times, and the precise ascertainment of its amount is very difficult. It may probably be estimated, on the average, at not less than one-tenth of the weight of the body.

19. The function of the blood is to supply nourishment to, and take away waste matters from, all parts of the body. It is absolutely essential to the life of every part of the body that it should be in such relation with a current of blood, that matters can pass freely from the blood to it, and from it to the blood, by transudation through the walls of the vessels in which the blood is contained. And this vivifying influence depends upon the corpuscles of the blood. The proof of these statements lies in the following experiments:—If the vessels of a limb of a living animal be tied in such a manner as to cut off the supply of blood from the limb, without affecting it in any other way, all the symptoms of death will set in. The limb will grow pale and cold, it will lose its sensibility, and volition will no longer have power over it; it will stiffen, and eventually mortify and decompose.

But, even when the death stiffening has begun to set in, if the ligatures be removed, and the blood be allowed to flow into the limb, the stiffening speedily ceases, the temperature of the part rises, the sensibility of the skin returns, the will regains power over the muscles, and, in short, the part returns to its normal condition.

If, instead of simply allowing the blood of the animal operated upon to flow again, such blood, deprived of its fibrin by whipping, but containing its corpuscles, be artificially passed through the vessels, it will be found as effectual a restorative as entire blood; while, on the other hand, the serum (which is equivalent to whipped blood without its corpuscles) has no such effect.

It is not necessary that the blood thus artificially injected should be that of the subject of the experiment. Men, or dogs, bled to apparent death may be at once and effectually revived by filling their veins with blood taken from another man, or dog, an operation which is known by the name of *transfusion.*

Nor is it absolutely necessary for the success of this operation that the blood used in transfusion should belong to an animal of the same species. The blood of a horse will permanently revive an ass, and, speaking generally, the blood of one animal may be replaced without injurious effects by that of another closely-allied species; while that of a very different animal will be more or less injurious, and may even cause immediate death.

20. The *Lymph*, which fills the lymphatic vessels, is, like the blood, an alkaline fluid, consisting of a plasma and corpuscles, and coagulates by the separation of fibrin from the plasma. The lymph differs from the blood in its corpuscles being all of the colourless kind, and in the very small proportion of its solid constituents, which amount

to only about 5 per cent. of its weight. Lymph may, in fact, be regarded as blood *minus* its red corpuscles, and diluted with water, so as to be somewhat less dense than the serum of blood, which contains about 8 per cent. of solid matters.

A quantity of fluid equal to that of the blood is probably poured into the blood, daily, from the lymphatic system. This fluid is in great measure the mere overflow of the blood itself—plasma which has exuded from the capillaries into the tissues, and which has not been taken up again into the venous current; the rest is due to the absorption of chyle from the alimentary canal.

LESSON IV.

RESPIRATION.

1. THE blood, the general nature and properties of which have been described in the preceding Lesson, is the highly complex product, not of any one organ or constituent of the body, but of all. Many of its features are doubtless given to it by its intrinsic and proper structural elements, the corpuscles; but the general character of the blood is also profoundly affected by the circumstance that every other part of the body takes something from the blood and pours something into it. The blood may be compared to a river, the nature of the contents of which is largely determined by that of the head waters, and by that of the animals which swim in it; but which is also very much affected by the soil over which it flows, by the water-weeds which cover its banks, and by affluents from distant regions; by irrigation works which are supplied from it, and by drain pipes which flow into it.

2. One of the most remarkable and important of the changes effected in the blood is that which results, in most parts of the body, from its simply passing through capillaries, or, in other words, through vessels, the walls of which are thin enough to permit a free exchange between the blood and the fluids which permeate the adjacent tissues (Lesson II. § 1).

Thus, if blood be taken from the artery which supplies a limb, it will be found to have a bright scarlet colour; while blood drawn, at the same time, from the vein of the limb, will be of a purplish hue, so dark that it is commonly called "black blood." And as this contrast is met with in the contents of the arteries and veins in general (except the pulmonary artery and veins), the scarlet blood is commonly known as *arterial*, and the black blood as *venous*.

This conversion of arterial into venous blood takes place in most parts of the body, while life persists. Thus, if a limb be cut off and scarlet blood be forced into its arteries by a syringe, it will issue from the veins as black blood, so long as the limb exhibits signs of persistent vitality; and when these disappear, the blood will no longer be changed.

3. When specimens of venous and of arterial blood are subjected to chemical examination, the differences presented by their solid and fluid constituents, are found to be very small and inconstant. As a rule, there is rather more water in arterial blood, and rather more fatty matter. But the gaseous contents of the two kinds of blood differ widely in the proportion which the carbonic acid gas bears to the oxygen; there being a smaller quantity of oxygen and a greater quantity of carbonic acid, in venous than in arterial blood.

And it may be experimentally demonstrated that this difference in their gaseous contents is the only essential difference between venous and arterial blood. For if arterial blood be shaken up with carbonic acid, so as to be thoroughly saturated with that gas, it loses oxygen, gains carbonic acid, and acquires the hue and properties of venous blood; while, if venous blood be similarly treated with oxygen, it gains oxygen, loses carbonic acid, and takes on the colour and properties of arterial blood.

The same result is attained, though more slowly, if the blood, in either case, be received into a bladder, and then placed in the carbonic acid, or oxygen gas; the thin moist animal membrane allowing the change to be effected with perfect ease, and offering no serious impediment to the passage of either gas.

4. The physico-chemical processes involved in the exchange of carbonic acid for oxygen when venous is converted into arterial blood, or the reverse, in the cases mentioned above, are not thoroughly understood, and are probably somewhat complex.

It is known (*a*) that gases, mechanically held by a fluid in a given proportion, tend to diffuse into any atmosphere to which they are exposed, until they occupy that atmosphere in corresponding proportions; and (*b*) that gases separated by a dry porous partition, or simply in contact, diffuse into one another with a rapidity which is inversely proportioned to the square roots of their densities. A knowledge of these physical principles does, in a rough way, lead us to see how the gases contained in the blood may effect an exchange with those in the air, whether the blood be freely exposed, or inclosed in a membrane.

But the application of these principles gives no more than this sort of general insight. For, in the first place, the gases of the blood are not held in a merely mechanical way in it; the oxygen seems to be loosely combined with the red corpuscles (Lesson III. § 16), and there is reason to think that a great part, at least, of the carbonic acid, is chemically connected, in a similarly loose way, with certain saline constituents of the serum. And, secondly, when arterialization takes place through the walls of a bladder, or any other thin animal membrane, the matter is still further complicated by the circumstance that moisture dissolves carbonic acid far more freely than it will oxygen; hence the wet bladder has a very different action upon carbonic acid from that which it has upon oxygen. A moist bladder, partially filled with oxygen, and suspended in carbonic acid gas, becomes rapidly distended, in consequence of the carbonic acid gas passing into it with much greater rapidity than the oxygen passes out.

5. The cause of the change of colour in the blood —of its darkening when exposed to carbonic acid, and its brightening when under the influence of oxygen—is not thoroughly understood. There is reason to think, however, that the red corpuscles are rendered somewhat flátter by oxygen gas, while they are distended by the action of carbonic acid (Lesson III. § 4). Under the former circumstances they may, not improbably, reflect the light more strongly, so as to give a more distinct coloration to the blood; while, under the latter, they may reflect less light, and, in that way, allow the blood to appear darker and duller.

This, however, is not the whole of the matter; for solutions of hæmoglobin or of blood crystals (Lesson III. § 9), even when perfectly free from actual blood-corpuscles, change in colour from scarlet to purple, according as they gain or lose oxygen. It has already been stated (Lesson III. § 16) that oxygen most probably exists in the blood in loose combination with hæmoglobin. But, further, there is evidence to show that a solution of hæmoglobin, when thus loosely combined with oxygen, has a scarlet colour, while a solution of hæmoglobin, deprived of oxygen, has a purplish hue. Hence arterial blood, in which the hæmoglobin is richly provided with oxygen, would naturally be scarlet, while venous blood, which not only contains an excess of carbonic acid, but whose hæmoglobin also has lost a great deal of its oxygen, would be purple.

6. Whatever may be their explanation, however, the facts are certain, (1) that arterial blood, separated by only a thin membrane from carbonic acid, or from a fluid containing a greater amount of carbonic acid than itself, becomes venous; and (2) that venous blood, separated by only a thin membrane from oxygen, or a fluid containing a greater proportion of free oxygen than itself, becomes arterial.

In these facts lies the explanation of the conversion of scarlet blood into dark blood as it passes through the capillaries of the body, for the latter are bathed by the juices of the tissues, which contain carbonic acid, the product of their waste and combustion, in excess. On the other hand, if we seek for the explanation of the conversion of the dark blood in the veins into the scarlet blood of the arteries, we find, 1st, that the blood remains dark in the right auricle, the right ventricle, and the pulmonary artery; 2d, that it is scarlet not only in the aorta, but in the left ventricle, the left auricle, and the pulmonary veins.

Obviously, then, the change from venous to arterial takes place in the pulmonary capillaries, for these are the sole channels of communication between the pulmonary arteries and the pulmonary veins.

7. But what are the physical conditions to which the blood is exposed in the pulmonary capillaries?

These vessels are very wide, thin walled, and closely set, so as to form a network with very small meshes, which is contained in the substance of an extremely thin membrane. This membrane is in contact with the air, so that the blood in each capillary of the lung is separated from the air, by only a delicate pellicle, formed by its own wall and the lung membrane. Hence an exchange very readily takes place between the blood and the air; the latter gaining moisture and carbonic acid, and losing oxygen (Lesson I. § § 23, 24).*

This is the essential step in respiration: that it really takes place may be demonstrated very readily, by the experiment described in the first Lesson (§ 3), in which air expired was proved to differ from air inspired, by containing more heat, more water, more carbonic acid, and less oxygen; or, on the other hand, by putting a ligature on the windpipe of a living animal so as to prevent air from passing into, or out of, the lungs, and then examining the contents of the heart and great vessels. The blood on both sides of the heart, and in the pulmonary veins and aorta, will be found to be as completely venous, as in the vena cava and pulmonary artery.

But though the passage of carbonic acid gas and hot watery vapour out of the blood, and of oxygen into it, is the essence of the respiratory process—and thus a membrane with blood on one side, and

* The student must guard himself against the idea that arterial blood contains no carbonic acid, and venous blood no oxygen. In passing through the lungs venous blood loses only a part of its carbonic acid; and arterial blood, in passing through the tissues, loses only a part of its oxygen. In blood, however venous, there is in health always some oxygen; and in even the brightest arterial blood there is actually more carbonic acid than oxygen.

air on the other, is all that is absolutely necessary to effect the purification of the blood—yet the accumulation of carbonic acid is so rapid, and the need for oxygen so incessant, in all parts of the human body,

Fig. 19.—Back View of the Neck and Thorax of a Human Subject from which the vertebral column and whole posterior wall of the Chest are supposed to be removed.

M. mouth; *Gl.* glottis; *Tr.* trachea; *L.L.* left lung; *R.L.* right lung; *Br.* bronchus; *P.A.* pulmonary artery; *P.V.* pulmonary veins; *Ao.* aorta; *D.* diaphragm; *H.* heart; *V.C.I.* Vena cava inferior.

that the former could not be cleared away, nor the latter supplied, with adequate rapidity, without the aid of extensive and complicated accessory machinery—the arrangement and working of which must next be carefully studied.

8. The back of the mouth or *pharynx* communicates by two channels with the external air (see Fig. 34). One of these is formed by the nasal passages, which cannot be closed by any muscular apparatus of their own; the other is presented by the mouth, which can be shut or opened at will.

Immediately behind the tongue, at the lower and front part of the pharynx, is an aperture—the *glottis*—capable of being closed by a sort of lid—the *epiglottis*—or by the shutting together of its side boundaries, formed by the so-called *vocal chords* (see (Figs. 34, 48, and 49). The glottis opens into a chamber with cartilaginous walls—the *larynx;* and leading from the larynx downwards along the front part of the throat, where it may be very readily felt, is the *trachea*, or windpipe (Fig. 19, *Tr.*).

If the trachea be handled through the skin, it will be found to be firm and resisting. Its walls are, in fact, strengthened by a series of cartilaginous hoops, which hoops are incomplete behind, their ends being united only by muscle and membrane, where the trachea comes into contact with the gullet, or *œsophagus*. The trachea passes into the thorax, and there divides into two branches, a right and a left, which are termed the *bronchi* (Fig. 19, *Br.*). Each bronchus enters the lung of its own side and then breaks up into a great number of smaller branches, which are called the *bronchial tubes*. As these diminish in size, the cartilages, which are continued all through the bronchi and their large ramifications, become smaller and eventually disappear, so that the walls of the smallest bronchial tubes are entirely muscular or membranous. Thus, while the trachea and bronchi are kept permanently open and pervious to air by their cartilages, the smaller bronchial tubes may be almost closed by the contraction of their muscular walls.

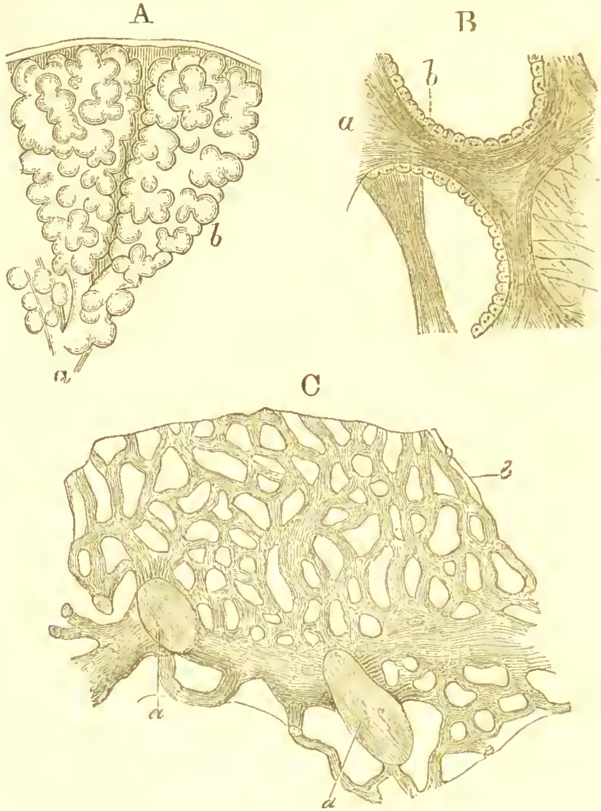

Fig. 20.

A. Two air-cells (*b*) with the ultimate bronchial tube (*a*) which opens into them. Magnified 20 diameters.

B. A section through the walls (*a*) of several air-cells with their epithelium (*b*).

C. The capillaries of part of the wall of an air-cell, magnified 300 diameters: *a*, cut ends of the smaller arteries and veins; *b*, wall of the air-cell.

The finer bronchial tubes end at length in elongated dilatations, about $\frac{1}{40}$th of an inch in diameter on the average, which are called the *air-cells,* and which have sacculated walls (Fig. 20, A). The very thin walls (Fig. 20, B) which separate these air-cells are supported by much delicate and highly elastic tissue, and carry the wide and close-set capillaries into which the ultimate ramifications of the pulmonary artery pour its blood (Fig. 20, C). Thus, the blood contained in these capillaries is exposed on both sides to the air—being separated from the air-cell on either hand only by the very delicate pellicle which forms the wall of the capillary, and the lining of the air-sac.

9. Hence no conditions can be more favourable to a ready exchange between the gaseous contents of the blood and those of the air in the air-cells, than the arrangements which obtain in the pulmonary capillaries; and, thus far, the structure of the lung fully enables us to understand how it is that the large quantity of blood poured through the pulmonary circulation becomes exposed in very thin streams, over a large surface, to the air. But the only result of this arrangement would be, that the pulmonary air would very speedily lose all its oxygen, and become completely saturated with carbonic acid, if special provision were not made for its being incessantly renewed.

10. If an adult man, breathing calmly in the sitting position, be watched, the respiratory act will be observed to be repeated thirteen to fifteen times every minute. Each act consists of certain components which succeed one another in a regular rhythmical order. First, the breath is drawn in, or *inspired;* immediately afterwards it is driven out, or

expired; and these successive acts of *inspiration* and *expiration* are followed by a brief pause. Thus, just as in the rhythm of the heart, the auricular systole, the ventricular systole, and then a pause follow in regular order; so in the chest, the inspiration, the expiration, and then a pause succeed one another. At each inspiration of an adult well-grown man about thirty cubic inches of air are inspired; and at each expiration the same, or a slightly smaller, volume (allowing for the increase of temperature of the air so expired) is given out of the body.

11. The expired air differs from the air inspired in the following particulars:—

(*a*) Whatever the temperature of the external air, that expired is nearly as hot as the blood, or has a temperature between 90° and 100°.

(*b*) However dry the external air may be, that expired is quite, or nearly, saturated with watery vapour.

(*c*) Though ordinary air contains nearly 2,100 parts of oxygen, and 7,900 of nitrogen, with not more than 3 parts of carbonic acid, in 10,000 parts, expired air contains about 470 parts of carbonic acid, and only between 1,500 and 1,600 parts of oxygen; while the quantity of nitrogen suffers little or no change. Speaking roughly, air which has been breathed once has gained five per cent. of carbonic acid, and lost five per cent. of oxygen.

The expired air contains, in addition, a greater or less quantity of animal matter of a highly decomposable character.

(*d*) Very close analysis of the expired air shows, firstly, that the quantity of oxygen which disappears is always slightly in excess of the quantity of carbonic acid supplied; and secondly, that the nitrogen is variable—the expired nitrogen being sometimes slightly in excess of, sometimes slightly less than that inspired, and sometimes remaining stationary.

12. From three hundred and fifty to four hundred cubic feet of air are thus passed through the lungs of an adult man taking little or no exercise, in the course of twenty-four hours; and are charged with carbonic acid, and deprived of oxygen, to the extent of nearly five per cent. This amounts to about eighteen cubic feet of the one gas taken in, and of the other given out. Thus, if a man be shut up in a close room, having the form of a cube seven feet in the side, every particle of air in that room will have passed through his lungs in twenty-four hours, and a fourth of the oxygen it contains will be replaced by carbonic acid.

The quantity of carbon eliminated in the twenty-four hours is pretty clearly represented by a piece of pure charcoal weighing eight ounces.

The quantity of water given off from the lungs in the twenty-four hours varies very much, but may be taken on the average as rather more than half a pint, or about nine ounces. It may fall below this amount, or increase to double or treble the quantity.

13. The mechanical arrangements by which the respiratory movements, essential to the removal of the great mass of effete matters, and the importation of the large quantity of oxygen indicated, are effected, may be found in—(*a*) the elasticity of the lungs; (*b*) the mobility of the sides and bottom of the thoracic cavity in which the lungs are contained.

The thorax may be regarded as a completely shut conical box, with the small end turned upwards, the back of the box being formed by the spinal column, the sides by the ribs, the front by the breast-bone, the bottom by the diaphragm, and the top by the root of the neck (Fig. 19).

The two lungs occupy almost all the cavity of this box which is not taken up by the heart. Each is inclosed in its serous membrane, the *pleura*. So long as the walls of the thorax are entire, the cavity of each pleura is practically obliterated, that layer of the pleura which covers the lung being in close contact with that which lines the wall of the chest; but if a small opening be made into the pleura, the lung at once shrinks to a comparatively small size, and thus develops a great cavity between the two layers of the pleura. If a pipe be now fitted into the bronchus, and air blown through it, the lung is very readily distended to its full size; but, on being left to itself, it collapses, the air being driven out again with some force. The abundant elastic tissues of the walls of the air-cells are, in fact, so disposed as to be greatly stretched when the lungs are full; and, when the cause of the distension is removed, this elasticity comes into play and drives the greater part of the air out again.

The lungs are kept distended in the dead subject, so long as the walls of the chest are entire, by the pressure of the atmosphere. For though the elastic tissue is all the while pulling, as it were, at the layer of pleura which covers the lung, and attempting to separate it from that which lines the chest, it cannot produce such a separation without developing a vacuum between these two layers. To effect this, the elastic tissue must pull with a force greater than that of the external air (or fifteen pounds to the square inch), an effort far beyond its powers, which do not equal more than one-fourth of a pound on the square inch. But the moment a hole is made in the pleura, the atmospheric pressure inside the lung is equalized by that outside it, and the elastic tissue, freed from its opponent, exerts its full power on the lung.

14. The lungs are elastic, whether alive or dead. During life the air which they contain may be further affected by the contractility of the muscular walls of the bronchial tubes. If water is poured into the lungs of a recently-killed animal, and a series of electric shocks is then sent through the bronchial tubes, the latter contract, and the water is forced out. Lastly, during life a further source of motion in the bronchial tubes is provided by the *cilia*—minute filaments attached to the epithelium of the tubes, which incessantly vibrate backwards and forwards, and work in such a manner as to sweep liquid and solid matters outwards, or towards the trachea.

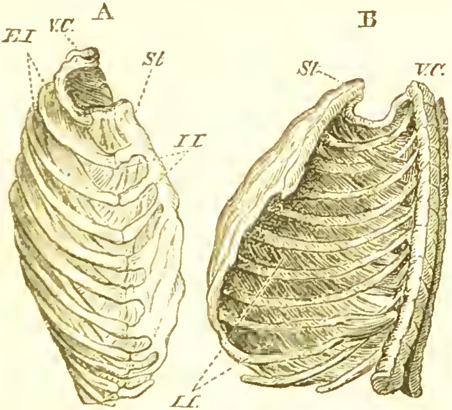

FIG. 21.—Showing, A, the external (*E.I.*) and, B, the internal (*I.I.*) intercostal muscles. In B the chest is supposed to be divided vertically through the middle of the breastbone (*St.*) and backbone (*V.C.*).

15. The ribs are attached to the spine, so as to be freely moveable upon it; but, when left to themselves, they take a position which is inclined obliquely downwards and forwards.* Two sets of muscles, called *intercostals,* pass between the successive pairs of ribs on each side. The outer set, called *external intercostals,* run from the rib above, obliquely downwards and forwards, to the rib below. The other set, *internal intercostals,* cross these in direction, passing from the rib above, downwards and backwards, to the rib below.

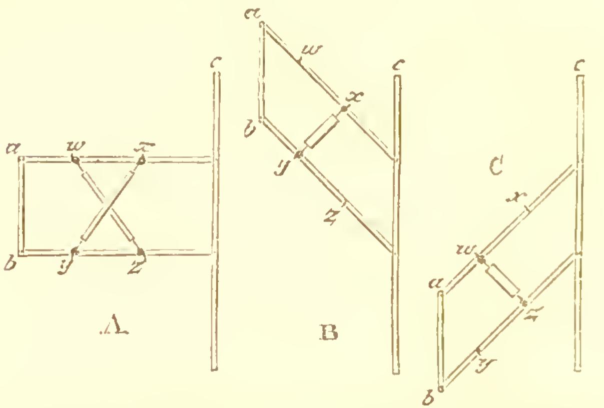

Fig 22.—Diagram of models illustrating the action of the external and internal intercostal muscles. B, inspiratory elevation; C, expiratory depression.

The action of these muscles is somewhat puzzling at first, but is readily understood if the fact that *when a muscle contracts, it tends to make the distance between its two ends as short as possible,* be borne in mind. Let *a* and *b* in Fig. 22, A, be two

* I purposely neglect the consideration of the cartilages of the ribs in order not to complicate the question unnecessarily.

parallel bars, moveable by their ends upon the upright *c*, which may be regarded as at the back of the apparatus, then a line directed from *x* to *y* will be inclined downwards and forwards, and one from *w* to *z* will be directed downwards and backwards. Now, it is obvious that there is one position of the rods, and one only, in which the points *x* and *y* are at the shortest possible distance, and one position only in which the points *w* and *z* are at the shortest possible distance; and these are, for *x* and *y* the position B, and for *w* and *z* the position C. These positions are respectively such that the points *x*, *y*, and *w*, *z*, are at the ends of straight lines perpendicular to both rods.

Thus, to bring *x* and *y* into this position, the parallel rods in A must move upwards; and to bring *w* and *z* into it, they must move in the opposite way.

If the simple apparatus just described be made of wood, hooks being placed at the points *x*, *y*, and *w*, *z*; and an elastic band, as long when left to itself as the shortest distance between these points, be provided with eyes which can be readily put on to or taken off these hooks: it will be found that when the bars are in the horizontal position, A, the elasticity of the band, when hooked on to *x* and *y*, will bring them up into the position shown in Fig. 22, B; while, if hooked on to *w* and *z*, it will force them down into the position shown in Fig. 22, C.

Substitute the contractility of the external and internal intercostal muscles for the elasticity of the band, and the latter will precisely exemplify their action; and it is thus proved that the external intercostals must raise, and the internal intercostals must depress, the bony ribs.

16. The diaphragm is a great partition situated between the thorax and the abdomen, and always concave to the latter and convex to the former (Fig. 1). From its middle, which is tendinous, muscular fibres extend downwards and outwards to the ribs, and two, especially strong masses, which are called the *pillars of the diaphragm*, to the spinal column (Fig. 23). When these muscular fibres contract, therefore, they tend to make the diaphragm flatter, and to increase the capacity of the thorax at the expense of that of the abdomen, by thrusting down the bottom of the thoracic box (Fig. 24, *A*).

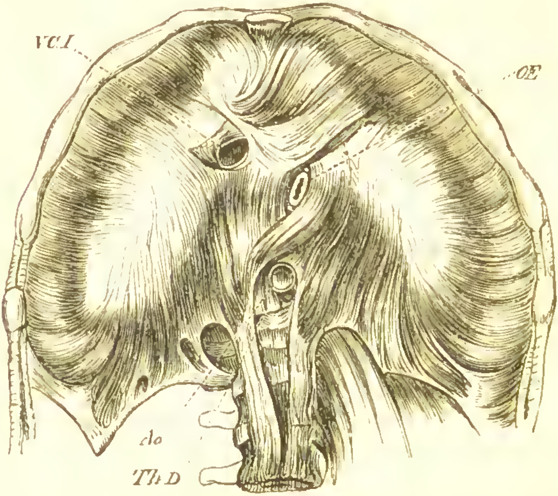

FIG. 23.—THE DIAPHRAGM VIEWED FROM THE LOWER OR ABDOMINAL SIDE

V.C.I., the vena cava inferior; *Œ*, the œsophagus; *Ao*, the aorta; *Th. D.*, the thoracic duct, cut where they pass through the diaphragm, the broad white tendinous middle of which is easily distinguished from the radiating muscular fibres which pass down to the ribs and into the pillars in front of the vertebræ

17. Let us now consider what would be the result of the action of the parts of the respiratory apparatus, which have been described, if the diaphragm alone should begin to contract at regular intervals.

When it contracts it increases the vertical dimensions of the thoracic cavity, and tends to pull away the lining of the bottom of the thoracic box from that which covers the base of the lungs; but the air immediately rushing in at the trachea, proportionately increases the distension of the lung, and prevents the formation of any vacuum between the two pleuræ in this region. When the diaphragm ceases to contract, so much of the elasticity of the lungs as was neutralized by the contraction of the diaphragm, comes into play, and the extra air taken in is driven out again. We have, in short, an *Inspiration* and an *Expiration*.

Suppose on the other hand that, the diaphragm being quiescent, the external intercostal muscles contract. The ribs will be raised from their oblique position, the antero-posterior dimensions of the thoracic cavity will be increased, and the lungs will be distended as before to balance the enlargement. If now the external intercostals relax, the action of gravity upon the ribs, and the elasticity of the lungs, will alone suffice to bring back the ribs to their previous positions and to drive out the extra air; but this expiratory action may be greatly aided by the contraction of the internal intercostals.

18. Thus it appears that we may have either *diaphragmatic respiration*, or *costal respiration*. As a general rule, however, not only do the two forms of respiration coincide and aid one another—the contraction of the diaphragm taking place at the

same time with that of the external intercostals, and its relaxation with the contraction of the internal intercostals—but sundry other accessory agencies come into play. Thus, the muscles which connect the ribs with parts of the spine above them, and with the shoulder, may, more or less extensively, assist inspiration; while those which connect the ribs and breastbone with the pelvis, and form the front and side walls of the abdomen, are powerful aids to expiration. In fact they assist expiration in two ways: first, directly, by pulling down the ribs; and next, indirectly, by pressing the viscera of the abdomen upwards against the under surface of the diaphragm, and so driving the floor of the thorax upwards.

It is for this reason that, whenever a violent expiratory effort is made, the walls of the abdomen are obviously flattened and driven towards the spine, the body being at the same time bent forwards.

In taking a deep inspiration, on the other hand, the walls of the abdomen are relaxed and become convex, the viscera being driven against them by the descent of the diaphragm—the spine is straightened, the head thrown back, and the shoulders outwards, so as to afford the greatest mechanical advantage to all the muscles which can elevate the ribs.

19. It is a remarkable circumstance that the mechanism of respiration is somewhat different in the two sexes. In men, the diaphragm takes the larger share in the process, the upper ribs moving comparatively little; in women, the reverse is the case, the respiratory act being more largely the result of the movement of the ribs.

Sighing is a deep and prolonged inspiration.

"*Snifting*" is a more rapid inspiratory act, in which the mouth is kept shut, and the air made to pass through the nose.

Coughing is a violent expiratory act. A deep inspiration being first taken, the glottis is closed and then burst open by the violent compression of the air contained in the lungs by the contraction of the expiratory muscles, the diaphragm being re-

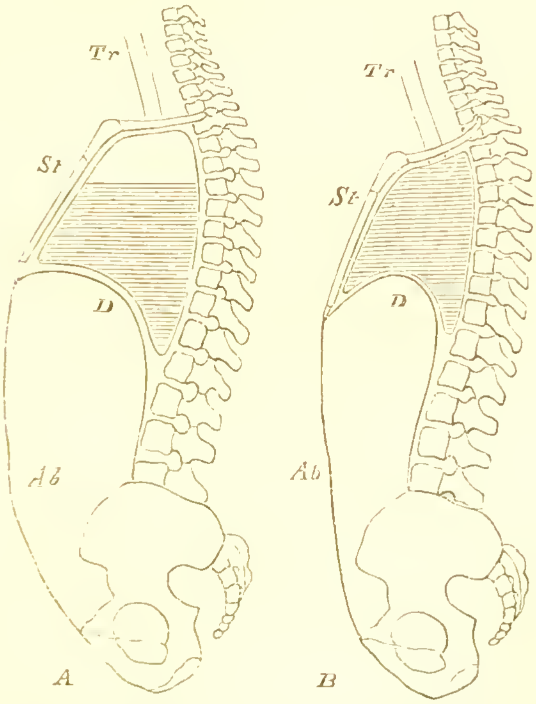

FIG. 24.—DIAGRAMMATIC SECTIONS OF THE BODY IN

A. inspiration; *B.* expiration. *Tr.* trachea; *St.* sternum; *D.* Diaphragm; *Ab.* abdominal walls. The shading roughly indicates the stationary air laxed and the air driven through the mouth. In *sneezing*, on the contrary, the cavity of the mouth being shut off from the pharynx by the approximation of the soft palate and the base of the tongue, the air is forced through the nasal passages.

20. It thus appears that the thorax, the lungs, and the trachea constitute a sort of bellows without a valve, in which the thorax and the lungs represent the body of the bellows, while the trachea is the pipe; and the effect of the respiratory movements is just the same as that of the approximation and separation of the handles of the bellows, which drive out and draw in the air through the pipe. There is, however, one difference between the bellows and the respiratory apparatus, of great importance in the theory of respiration, though frequently overlooked; and that is, that the sides of the bellows can be brought close together so as to force out all, or nearly all, the air which they contain; while the walls of the chest, when approximated as much as possible, still inclose a very considerable cavity (Fig. 24, *B*); so that, even after the most violent expiratory effort, a very large quantity of air is left in the lungs.

The amount of this air which cannot be got rid of, and is called *Residual air*, is, on the average, from 75 to 100 cubic inches.

About as much more in addition to this remains in the chest after an ordinary expiration, and is called *Supplemental air*.

In ordinary breathing, 20 to 30 cubic inches of what is conveniently called *Tidal air* pass in and out. It follows that, after an ordinary inspiration, $100+100+30=230$ cubic inches, may be contained in the lungs. By taking the deepest possible inspiration, another 100 cubic inches, called *Complemental air*, may be added.

21. It results from these data that the lungs, after an ordinary inspiration, contain about 230 cubic inches of air, and that only about one-seventh to one-eighth of this amount is breathed out and taken in again at the next inspiration. Apart from the circumstance, then, that the fresh air inspired has to fill the cavities of the hinder part of the mouth, and the trachea, and the bronchi, if the lungs were mere bags fixed to the ends of the bronchi, the inspired air would descend as far only as to occupy that one-fourteenth to one-sixteenth part of each bag which was nearest to the bronchi, whence it would be driven out again at the next expiration. But as the bronchi branch out into a prodigious number of bronchial tubes, the inspired air can only penetrate for a certain distance along these, and can never reach the air-cells at all.

Thus the residual and supplemental air taken together are, under ordinary circumstances, *stationary*—that is to say, the air comprehended under these names merely shifts its outer limit in the bronchial tubes, as the chest dilates and contracts, without leaving the lungs; the *tidal* air, alone, being that which leaves the lungs and is renewed in ordinary respiration.

It is obvious, therefore, that the business of respiration is essentially transacted by the stationary air, which plays the part of a middleman between the two parties—the blood and the fresh tidal air—who desire to exchange their commodities, carbonic acid for oxygen, and oxygen for carbonic acid.

Now there is nothing interposed between the fresh tidal air and the stationary air; they are aëriform fluids, in complete contact and continuity, and hence the exchange between them must take place according to the ordinary laws of gaseous diffusion.

22. Thus, the stationary air in the air-cells gives up oxygen to the blood, and takes carbonic acid from it, though the exact mode in which the change is effected is not thoroughly understood. By this process it becomes loaded with carbonic acid, and deficient in oxygen, though to what precise extent is not known. But there must be a very much greater excess of the one, and deficiency of the other, than is exhibited by inspired air, seeing that the latter acquires its composition by diffusion in the short space of time (four to five seconds) during which it is in contact with the stationary air.

In accordance with these facts, it is found that the air expired during the first half of an expiration contains less carbonic acid than that expired during the second half. Further, when the frequency of respiration is increased without altering the volume of each inspiration, though the percentage of carbonic acid in each inspiration is diminished, it is not diminished in the same ratio as that in which the number of inspirations increases; and hence more carbonic acid is got rid of in a given time.

Thus, if the number of inspirations per minute is increased from fifteen to thirty, the percentage of carbonic acid evolved in the second case remains more than half of what it was in the first case, and hence the total evolution is greater.

23. Of the various mechanical aids to the respiratory process, the nature and workings of which have now been described, one, the elasticity of the lungs, is of the nature of a dead, constant force. The action

of the rest of the apparatus is under the control of the nervous system, and varies from time to time.

As the nasal passages cannot be closed by their own action, air has always free access to the pharynx; but the glottis, or entrance to the windpipe, is completely under the control of the nervous system—the smallest irritation about the mucous membrane in its neighbourhood being conveyed, by its nerves, to that part of the cerebro-spinal axis which is called the *medulla oblongata* (see Lesson XI. § 16). The medulla oblongata, thus stimulated, gives rise, by a process which will be explained hereafter, termed *reflex action*, to the contraction of the muscles which close the glottis, and commonly, at the same time, to a violent contraction of the expiratory muscles, producing a cough (see § 19).

The muscular fibres of the smaller bronchial tubes, no less than the respiratory pump itself, formed by the walls and floor of the thorax, are under the complete control of the nerves which supply the muscles, and which are brought into action in consequence of impressions conveyed to that part of the brain which is called the medulla oblongata, by the pneumogastric and other nerves.

24. From what has been said, it is obvious that there are many analogies between the circulatory and the respiratory apparatus. Each consists, essentially, of a kind of pump which distributes a fluid (aëriform in the one case, liquid in the other) through a series of ramified distributing tubes to a system of cavities (capillaries or air-cells), the volume of the contents of which is greater than that of the tubes.

In each, the pump is the cause of the motion of the fluid, though that motion may be regulated, locally, by the contraction, or relaxation, of the muscular fibres contained in the walls of the distributing tubes. But, while the rhythmic movement of the heart chiefly depends upon a nervous apparatus placed within itself, that of the respiratory apparatus results mainly from the operation of a nervous centre lodged in the medulla oblongata.

25. As there are certain secondary phenomena which accompany, and are explained by, the action of the heart, so there are secondary phenomena which are similarly related to the working of the respiratory apparatus. These are—(*a*) the respiratory sounds, and (*b*) the effect of the inspiratory and expiratory movements upon the circulation.

26. The *respiratory sounds*, or *murmurs*, are audible when the ear is applied to any part of the chest which covers one or other of the lungs. They accompany inspiration and expiration, and very much resemble the sounds produced by breathing through the mouth, when the lips are so applied together as to leave a small interval. Over the bronchi the sounds are louder than over the general surface. It would appear that these sounds are produced by the motion of the air along the air-passages.

27. In consequence of the elasticity of the lungs, a certain force must be expended in distending them, and this force is found experimentally to become greater and greater the more the lung is distended; just as, in stretching a piece of india-rubber, more force is required to stretch it a good deal than is needed to stretch it only a little. Hence, when inspiration takes place, and the lungs are distended with air, the heart and the great vessels in the chest are subjected to a less pressure than are the blood-vessels of the rest of the body.

For the pressure of the air contained in the lungs is exactly the same as that exerted by the atmosphere upon the surface of the body; that is to say, fifteen pounds on the square inch. But a certain amount of this pressure exerted by the air in the lungs is counterbalanced by the elasticity of the distended lungs. Say that in a given condition of inspiration a pound pressure on the square inch is needed to overcome this elasticity, then there will be only fourteen pounds' pressure on every square inch of the heart and great vessels. And hence the pressure on the blood in these vessels will be one pound per square inch less than that on the veins and arteries of the rest of the body. If there were no aortic, or pulmonary, valves, and if the composition of the vessels, and the pressure upon the blood in them, were everywhere the same, the result of this excess of pressure on the surface would be, to drive all the blood from the arteries and veins of the rest of the body into the heart and great vessels contained in the thorax. And thus the diminution of the pressure upon the thoracic blood cavities produced by inspiration, would, practically, suck the blood from all parts of the body towards the thorax. But the suction thus exerted, while it hastened the flow of blood to the heart in the veins, would equally oppose the flow from the heart to the arteries, and the two effects would balance one another.

As a matter of fact, however, we know—

(1.) That the blood in the great arteries is constantly under a very considerable pressure, exerted by their elastic walls; while that of the veins is under little or no pressure, the walls of the veins having but little elasticity.

(2.) That the walls of the arteries are strong and resisting, while those of the veins are weak and flabby.

(3.) That the veins have valves opening towards the heart; and that, during the diastole, there is no resistance of any moment to the free passage of blood into the heart; while, on the other hand, the cavity of the arteries is shut off from that of the ventricle during the diastole, by the closure of the semilunar valves.

Hence it follows that equal pressures applied to the surface of the veins and to that of the arteries must produce very different effects. In the veins the pressure is something which did not exist before; and, partly from the presence of valves, partly from the absence of resistance in the heart, partly from the presence of resistance in the capillaries, it all tends to accelerate the flow of blood *towards* the heart. In the arteries, on the other hand, the pressure is only a fractional addition to that which existed before; so that, during the systole, it only makes a comparatively small addition to the resistance which has to be overcome by the ventricle; and during the diastole, it superadds itself to the elasticity of the arterial walls in driving the blood onwards towards the capillaries, inasmuch as all progress in the opposite direction is stopped by the semilunar valves.

It is, therefore, clear that the inspiratory movement, on the whole, helps the heart, inasmuch as its general result is to drive the blood the way that the heart propels it.

28. In expiration, the difference between the pressure of the atmosphere on the surface, and that which it exerts on the contents of the thorax through the lungs, becomes less and less in proportion to the

completeness of the expiration. Whenever, by the ascent of the diaphragm and the descent of the ribs, the cavity of the thorax is so far diminished that pressure is exerted on the great vessels, the veins, owing to the thinness of their walls, are especially affected, and a check is given to the flow of blood in them, which may become visible as a *venous pulse* in the great vessels of the neck. In its effect on the arterial trunks, expiration, like inspiration, is, on the whole, favourable to the circulation; the increased resistance to the opening of the valves during the ventricular systole being more than balanced by the advantage gained in the addition of the expiratory pressure to the elastic reaction of the arterial walls during the diastole.

When the skull of a living animal is laid open and the brain exposed, the cerebral substance is seen to rise and fall synchronously with the respiratory movements; the rise corresponding with expiration.

29. Hitherto, I have supposed the air-passages to be freely open during the inspiratory and expiratory movements. But if, the lungs being distended, the mouth and nose are closed, and a strong expiratory effort is then made, the heart's action may be stopped altogether.* And the same result occurs if, the lungs being partially emptied, and the nose and mouth closed, a strong inspiratory effort is made. In the latter case the excessive distension of the right side of the heart, in consequence of the flow of blood into it, may be the cause of the arrest of the heart's action; but in the former, the reason of the stoppage is not very clear.

* There is danger in attempting this experiment.

30. The activity of the respiratory process is greatly modified by the circumstances in which the body is placed. Thus, cold greatly increases the quantity of air which is breathed, the quantity of oxygen absorbed, and of carbonic acid expelled: exercise and the taking of food have a corresponding effect.

In proportion to the weight of the body, the activity of the respiratory process is far greatest in children, and diminishes gradually with age.

The excretion of carbonic acid is greatest during the day, and gradually sinks at night, attaining its minimum about midnight, or a little after.

Recent observations appear to show that the rule that the quantity of oxygen taken in by respiration is, approximately, equal to that given out by expiration, only holds good for the total result of twenty-four hours' respiration. Much more oxygen appears to be given out during the day-time (in combination with carbon as carbonic acid) than is absorbed; while, at night, much more oxygen is absorbed than is excreted as carbonic acid during the same period. And it is very probable that the deficiency of oxygen towards the end of the waking hours, which is thus produced, is one cause of the sense of fatigue which comes on at that time.

The quantity of oxygen which disappears in proportion to the carbonic acid given out, is greatest in carnivorous, least in herbivorous animals—greater in a man living on a flesh diet, than when the same man is feeding on vegetable matters.

31. When a man is strangled, drowned, or choked, or is, in any other way, prevented from inspiring or expiring sufficiently pure atmospheric air, what is called *asphyxia* comes on. He grows " black in the

face;" the veins become turgid; insensibility, not unfrequently accompanied by convulsive movements, sets in, and he is dead in a few minutes.

But, in this asphyxiating process, two deadly influeuces of a distinct nature are co-operating; one is the *deprivation of oxygen*, the other is the *excessive accumulation of carbonic acid* in the blood. Oxygen starvation and carbonic acid poisoning, each of which may be fatal in itself, are at work together.

The effects of oxygen starvation may be studied separately, by placing a small animal under the receiver of an air-pump and exhausting the air; or by replacing the air by a stream of hydrogen, or nitrogen gas. In these cases no accumulation of carbonic acid is permitted, but, on the other hand, the supply of oxygen soon becomes insufficient, and the animal quickly dies. And if the experiment be made in another way, by placing a small mammal, or bird, in air from which the carbonic acid is removed as soon as it is formed, the animal will nevertheless die as soon as the amount of oxygen is reduced to 10 per cent. or thereabouts.

The directly poisonous effect of carbonic acid, on the other hand, has been very much exaggerated. A very large quantity of pure carbonic acid (10 to 15 or 20 per cent.) may be contained in air, without producing any very serious immediate effect, if the quantity of oxygen be simultaneously increased. And it is possible that what appear to be the directly poisonous effects of carbonic acid may really arise from its taking up the room that ought to be occupied by oxygen. If this be the case, carbonic acid is a negative rather than a positive poison.

Whichever may be the more potent agency, the effect of the two, as combined in asphyxia, is to produce an obstruction, firstly, in the pulmonary circulation, and, secondly, in the veins of the body generally. The lungs and the right side of the heart, consequently, become gorged with blood, while the arteries and left side of the heart gradually empty themselves of the small supply of dark and unaërated blood which they receive. The heart becomes paralysed, partly by reason of the distension of its right side, partly from being supplied with venous blood; and all the organs of the body gradually cease to act.

32. Sulphuretted hydrogen, so well known by its offensive smell, has long had the repute of being a positive poison. But its evil effects appear to arise chiefly, if not wholly, from the circumstance that its hydrogen combines with the oxygen carried by the blood-corpuscles, and thus gives rise, indirectly, to a form of oxygen starvation.

Carbonic oxide gas has a much more serious effect, as it turns out the oxygen from the blood-corpuscles, and forms a combination of its own with the hæmoglobin. The compound thus formed is gradually decomposed by fresh oxygen; but, if any large proportion of the blood-corpuscles be thus rendered useless, the animal dies before this restoration can be effected.

Badly made common gas sometimes contains 20 to 30 per cent. of carbonic oxide; and, under these circumstances, a leakage of the pipes in a house may be extremely perilous to life.

33. It is not necessary, however, absolutely to strangle, or drown, a man in order to asphyxiate him. As, other things being alike, the rapidity of diffusion between two gaseous mixtures depends on

the difference of the proportions in which their constituents are mixed, it follows that the more nearly the composition of the tidal air approaches that of the stationary air, the slower will be the diffusion of carbonic acid outwards and of oxygen inwards, and the more charged with carbonic acid and defective in oxygen will the air in the air-cells become. And, on increasing the proportion of carbonic acid in the tidal air, a point will at length be reached when the change effected in the stationary air is too slight to enable it to relieve the pulmonary blood of its carbonic acid, and to supply it with oxygen to the extent required for its arterialization. In this case the blood, which passes into the aorta, and is thence distributed to the heart and the body generally, being venous, all the symptoms of insensibility, loss of muscular power, and the like, which have been enumerated above as the results of supplying the brain and muscles with venous blood, will follow, and a stage of suffocation, or asphyxia, will supervene.

34. Asphyxia takes place whenever the proportion of carbonic acid in tidal air reaches 10 per cent. (the oxygen being diminished in like proportion). And it makes no difference whether the quantity of carbonic acid in the air breathed is increased by shutting out fresh air; or by augmenting the number of persons who are consuming the same air; or by suffering combustion, in any shape, to carry off oxygen from the air.

But the deprivation of oxygen, and the accumulation of carbonic acid, cause injury, long before the asphyxiating point is reached. Uneasiness and headache arise when less than one per cent. of the oxygen of the air is replaced by other matters; while the persistent breathing of such air tends to lower all kinds of vital energy, and predisposes to disease.

Hence the necessity of sufficient air and of ventilation for every human being. To be supplied with respiratory air in a fair state of purity, every man ought to have at least 800 cubic feet of space* to himself, and that space ought to be freely accessible, by direct or indirect channels, to the atmosphere.

* A cubical room nine feet high, wide and long, contains only 729 cubic feet of air.

LESSON V.

THE SOURCES OF LOSS AND OF GAIN TO THE BLOOD.

1. The blood which has been aërated, or arterialized, by the process described in the preceding Lesson, is carried from the lungs by the pulmonary veins to the left auricle, and is then forced by the auricle into the ventricle, and by the ventricle into the aorta. As that great vessel traverses the thorax, it gives off several large arteries, by means of which blood is distributed to the head, the arms, and the walls of the body. Passing through the diaphragm (Fig. 23), the aortic trunk enters the cavity of the abdomen, and becomes what is called the *abdominal aorta*, from which vessels are given off to the viscera of the abdomen. Finally, the main stream of blood flows into the *iliac* arteries, whence the viscera of the pelvis and the legs are supplied.

Having traversed the ultimate ramifications of the arteries, the blood, as we have seen, enters the capillaries. Here, the products of the waste of the tissues constantly pour into it; and, as the blood is everywhere full of corpuscles, which, like all other living things, decay and die, the results of their decomposition everywhere accumulate in it. It follows that, if the blood is to be kept pure, the waste matters thus incessantly poured into, or generated in it, must be as constantly got rid of, or excreted.

2. Three distinct sets of organs are especially charged with this office of continually excreting carbonic acid, water, and urea. They are the *Lungs*, the *Kidneys*, and the *Skin* (see Lesson I. § 23). These three great organs may therefore be regarded as so many drains from the blood—as so many channels by which it is constantly losing substance.

Further, the blood, as it passes through the capillaries, is constantly losing matter by exudation into the surrounding tissues.

Another kind of loss takes place from the surface of the body generally, and from the interior of the air-passages and lungs. Heat is constantly being given off from the former by radiation, evaporation, and conduction; from the latter, chiefly by evaporation.

3. The blood which enters the liver is constantly losing material to that organ; but the loss is only temporary, as almost all the matter lost, converted into sugar and into bile, re-enters the current of the circulation in the liver itself, or elsewhere.

Again, the loss of matter by the lungs in expiration is partially made good by the no less constant gain which results from the quantity of oxygen absorbed at each inspiration: while the combustion which is carried on in the tissues, by means of this oxygen, is the source not only of the heat which is given off through the lungs, but also of that which is carried away from the general surface of the body. And the loss by exudation from the capillaries is, in some degree, compensated by the gain from the lymphatics and ductless glands.

4. In the instances just mentioned the loss and gain are constant, and go on while life and health last. But there are certain other operations which

cause either loss or gain to the blood, and which are not continuous, but take place at intervals.

These are, on the side of loss, the actions of the many *secretory glands*, which separate certain substances from the blood at recurrent periods, in the intervals of which they are quiescent.

On the side of gain are the contractions of the *muscles*, which, during their activity, cause a great quantity of waste materials to appear in the blood; and the operations of the *alimentary canal*, which, for a certain period after food has been taken, pour new materials into the blood.

Under some circumstances, the skin, by absorbing fluids, may become a source of gain.

5. The sources of loss and gain to the blood may be conveniently arranged in the following tabular form:—

A. Incessantly active Sources of Loss or Gain to the Blood.*

a. Sources of loss.

I. *Loss of matter.*

1. The lungs.
2. The kidneys.
3. The skin.
4. The liver.
5. The tissues generally.

II. *Loss of heat.*

1. The free surfaces of the body.

* The learner must be careful not to confound the losses and gains of the *blood* with the losses and gains of the *body* as a whole. The two differ in much the same way as the internal commerce of a country differs from its export and import trade.

b. The sources of gain.

I. *Gain of matter.*

1. The lungs.
2. The liver.
3. The spleen, ductless glands, and lymphatic system.
4. The tissues generally.

II. *Gain of heat.*

1. The blood itself and the tissues generally.

B. INTERMITTENTLY ACTIVE SOURCES OF LOSS OR GAIN TO THE BLOOD.

a. Source of loss.

1. Many secreting glands.

b. Sources of gain.

1. The muscles.
2. The alimentary canal.
3. The skin.

6. In the preceding Lesson I have described the operation by which the lungs withdraw from the blood much carbonic acid and water, with a fractional quantity of urea, and supply oxygen to the blood; I now proceed to the second source of continual loss, the KIDNEYS.

Of these organs, there are two, placed at the back of the abdominal cavity, one on each side of the lumbar region of the spine. Each, though somewhat larger than the kidney of a sheep, has a similar shape. The depressed, or concave, side of the kidney is turned inwards, or towards the spine; and its convex side is directed outwards (Fig. 25). From the middle of the concave side (called the *hilus*) of each kidney, a long tube with a small bore, the *Ureter* (*Ur.*), proceeds to the Bladder (*Bl.*).

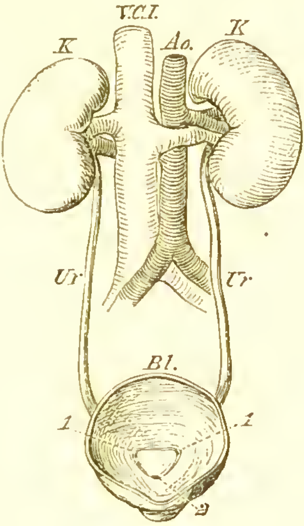

FIG. 25.

The kidneys (*K*); ureters (*Ur.*); with the aorta (*Ao.*), and vena cava inferior (*V.C.I.*); and the renal arteries and veins. *Bl.* is the bladder, the top of which is cut off so as to show the openings of the ureters (1, 1) and that of the urethra (2).

The latter, situated in the pelvis, is an oval bag, the walls of which contain abundant unstriped muscular fibre, while it is lined, internally, by mucous membrane, and coated externally by the peritoneum. The ureters open side by side, but at some little distance from one another, on the posterior and inferior wall of the bladder (Fig. 25, 1, 1). In front of them is a single aperture which leads into the canal called the *Urethra* (Fig. 25, 2), by which the cavity of the bladder is placed in communication with the exterior of the body. The openings of the ureters enter the walls of the bladder obliquely, so that it is much more easy for fluid to pass from the ureters into the bladder than for it to get the other way, from the bladder into the ureters.

Mechanically speaking, there is little obstacle to the free flow of fluid from the ureters into the bladder, and from the bladder into the urethra, and so outwards; but certain muscular fibres arranged circularly around the part called the "neck" of the bladder, where it joins the urethra, constitute what is termed a *sphincter*, and are usually, during life, in a state of contraction, so as to close the exit of the bladder, while the other muscular fibres of the organ are relaxed.

It is only at intervals that this state of matters is reversed; and the walls of the bladder contracting, while its sphincter relaxes, its contents, the *urine*, are discharged. But, though the expulsion of the secretion of the kidneys from the body is thus intermittent, the excretion itself is constant, and the urinary fluid flows, drop by drop, from the opening of the ureters into the bladder. Here it accumulates, until its quantity is sufficient to give rise to the uneasy sensations which compel its expulsion.

7. The excretion of nitrogenous waste and water, with a little carbonic acid, by the kidneys, is thus strictly comparable to that of carbonic acid and water, with a little urea, by the lungs, in the air-cells of which carbonic acid and watery vapours are incessantly accumulating, to be periodically expelled by the act of expiration. But the operation of the

renal apparatus differs from that of the respiratory organs, in the far longer intervals between the expulsory acts; and still more in the circumstance that, while the substance which the lungs take into the body is as important as those which they give out, the kidneys take in nothing.

8. The renal excretion has naturally an acid reaction, and consists of *urea* and *uric acid*, sundry other animal products of less importance including certain colouring matters; with saline and gaseous substances, held in solution by a large quantity of water.

The quantity and composition of the urine vary greatly according to the time of day; the temperature and moisture of the air; the fasting or replete condition of the alimentary canal: and the nature of the food.

Urea and uric acid are both composed of the elements carbon, hydrogen, oxygen, and nitrogen, but the urea is by far the more soluble in water, and greatly exceeds the uric acid in quantity.

An average healthy man excretes by the kidneys about fifty ounces, or 24,000 grains, of water a day. In this are dissolved 500 grains of urea, but not more than 10 to 12 grains of uric acid.

The amount of other animal matters, and of saline substances, varies from one-third as much, to nearly the same amount as, the urea. The saline matters consist chiefly of common salt, phosphates and sulphates of potash, soda, lime, and magnesia. The gases are the same as those in the blood,—namely, carbonic acid, oxygen, and nitrogen. But the quantity is, proportionally, less than one-third as great; and the carbonic acid is in very large, while the oxygen is in very small, amount.

The average specific gravity does not differ very widely from that of blood serum, being 1·020.

9. It will be observed that all the chief constituents of the urine are already contained in the blood, and indeed, it might almost be said to be the blood devoid of its corpuscles, fibrin, and albumen. Speaking broadly, it is such a fluid as might be separated from the blood by the help of any kind of filter which had the property of retaining these constituents, and letting the rest flow off. The filter required is found in the kidney, with the minute structure of which it is now necessary to become acquainted.

When a longitudinal section of a kidney is made (Fig. 26), the upper end of the ureter (*U*) seems to widen out into a basin-like cavity (*P*), which is called the *pelvis* of the kidney. Into this, sundry conical elevations, called the *Pyramids* (*Py*) project; and their summits present multitudes of minute openings—the final terminations of the *tubuli*, of which the thickness of the kidney is chiefly made up. If the tubules be traced from their openings towards the outer surface, they are found, at first, to lie parallel with one another in bundles, which radiate towards that surface, and subdivide as they go; but at length they spread about irregularly, and become interlaced. From this circumstance alone, the middle, or *medullary*, part (marrow, *medulla*) of the kidney looks different from the superficial, or *cortical*, part (bark, *cortex*); but, in addition, the cortical part is more abundantly supplied with vessels than the medullary, and hence has a darker aspect. The great majority of the tubules ultimately terminate in dilatations (Fig. 27), which are called *Malpighian capsules.* Into the summit of each capsule, a small vessel (*f*), one of the ultimate branches of the *renal artery* (Fig. 26, *R A*), enters (driving the thin wall of the capsule before it), and immediately breaks up into a bunch of looped capillaries, called a *glomerulus* (Fig. 27.

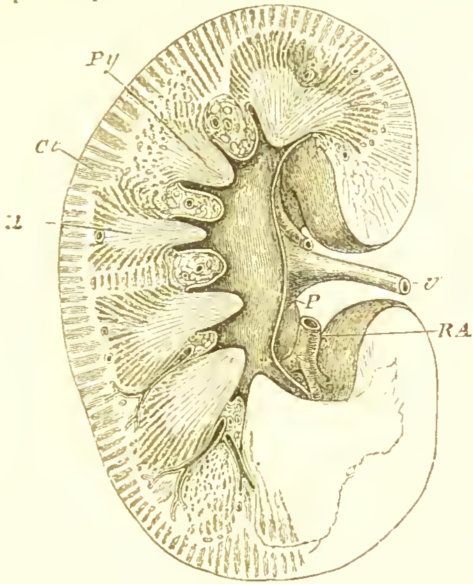

Fig. 26.

Longitudinal section of the human kidney. *Ct.* the cortical substance; *M*, the medullary substance; *P*, the pelvis of the kidney; *U*, the ureter; *R A*, the renal artery: *Py*, a pyramid.

h), which nearly fills the cavity of the capsule. The blood is carried away from this *glomerulus* by a small vein (*g*) which does not, at once, join with other veins into a larger venous trunk, but opens into the net-work of capillaries which surrounds the tubule, thus repeating the portal circulation on a small scale.

The tubule has an epithelial lining (*d*), continuous with that of the pelvis of the kidney, and the urinary passages generally. The epithelium is thick and plain enough in the tubule, but it becomes very delicate, or even disappears, in the capsule and on the glomerulus.

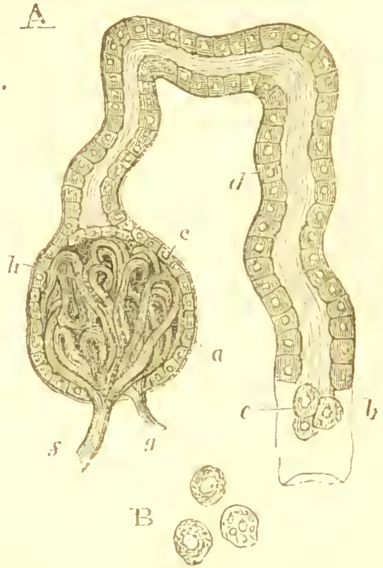

FIG. 27.

Magnified about 300 diameters

A. Malpighian capsule (*a*), with its contained glomerulus (*h*) and the beginning of the tubule (*b*) into which it opens. *c*, *d*, epithelium, in place; *e*, epithelium of the tubule detached; *f*, the artery; *g*, the vein; *h*, the glomerulus. *B*. The epithelium magnified.

10. It is obvious from this description, that the surface of the glomerulus is, practically, free, or in direct communication with the exterior by means of the cavity of the tubule; and further, that, in each vessel of the glomerulus, a thin stream of blood constantly flows, only separated from the cavity of the tubule by the very delicate membrane of which

the wall of the vessel is composed. The Malpighian capsule may, in fact, be regarded as a funnel, and the membranous walls of the glomerulus as a piece of very delicate filtering-paper, into which the blood is poured.

11. The blood which supplies the kidneys is brought directly from the aorta by the renal arteries, so that it has but shortly left the heart. The venous blood which enters the heart, and is propelled to the lungs, charged with the nitrogenous, as well as with the other, products of waste, loses only an inappreciable quantity of the former in its course through the lungs; so that the arterial blood which fills the aorta is pure only as regards carbonaceous waste, while it is impure as regards urea and uric acid.

In the healthy condition, the walls of the minute renal arteries and veins are relaxed, so that the passage of the blood is very free; and but little waste, arising from muscular contraction in the walls of these vessels, is thrown into the renal blood. And as the urine which is separated from the renal blood contains proportionately less oxygen and more carbonic acid than the blood itself, any gain of carbonic acid from this source is probably at once counterbalanced. Hence, so long as the kidney is performing its functions properly, the blood which leaves the organ by the renal vein is as bright scarlet as that which enters it by the renal artery. Strictly speaking, it is the purest blood in the body, careful analysis having shown that it contains a sensibly smaller quantity of urea and of water than that of the left side of the heart. This difference is, of course, a necessary result of the excretion of the urinary fluid from the blood as it travels through the kidney.

As the renal veins pour their contents directly into the inferior vena cava (see Fig. 25), it follows that the blood in the upper part of this vein is far less impure, or venous, than that contained in the inferior vena cava, below the renal veins.

12. Irritation of the nerves which supply the walls of the vessels of the kidney has the immediate effect of stopping the excretion of urine, and rendering the renal blood dark and venous. The first effect would appear to be explicable by the diminution of the pressure exerted upon the blood in the Malpighian tufts, in consequence of the diminution in the size of the channels—the small arteries—by which the blood reaches them. And the second effect is probably, in part, a secondary result of the first—the excretion of carbonic acid by the urine ceasing with the suppression of that fluid; while, to a large extent, it is also the result of a pouring in of carbonic acid into the renal blood, in consequence of the work of the muscles of the small vessels, and the waste which results therefrom.

13. That the *skin* is a source of continual loss to the blood may be proved in various ways. If the whole body of a man, or one of his limbs, be inclosed in a caoutchouc bag, full of air, it will be found that this air undergoes changes which are similar in kind to those which take place in the air which is inspired into the lungs. That is to say, the air loses oxygen and gains carbonic acid; it receives a great quantity of watery vapour, which condenses upon the sides of the bag, and may be drawn off by a properly disposed pipe; and a minute quantity of urea accumulates upon the surface of the limb or body.

Under ordinary circumstances no liquid water appears upon the surface of the integument, and the whole process receives the name of the *insensible perspiration*. But, when violent exercise is taken, or under some kinds of mental emotion, or when the body is exposed to a hot and moist atmosphere, the perspiration becomes *sensible;* that is, appears in the form of scattered drops upon the surface.

14. The quantity of *sweat*, or *perspiration*, varies immensely, according to the temperature and other conditions of the air, and according to the state of the blood and of the nervous system. It is estimated that, as a general rule, the quantity of water excreted by the skin is about double that given out by the lungs in the same time. The quantity of carbonic acid is not above $\frac{1}{30}$th or $\frac{1}{40}$th of that excreted by the lungs. The precise quantity of urea excreted is not known.

In its normal state the sweat is acid, and contains fatty matters, even when obtained free from the fatty products of the *sebaceous glands*. Ordinarily, perspiration, as it collects upon the skin, is mixed with the fatty secretion of these glands; and, in addition, contains scales of the external layers of the epidermis, which are constantly being shed.

15. In analysing the process by which the perspiration is eliminated from the body, it must be recollected, in the first place, that the skin, even if there were no glandular structures connected with it, would be in the position of a moderately thick, permeable membrane, interposed between a hot fluid, the blood, and the atmosphere. Even in hot climates the air is, usually, far from being completely saturated with watery vapour, and in temperate climates it ceases to be so saturated the moment it

comes into contact with the skin, the temperature of which is, ordinarily, twenty or thirty degrees above its own.

A bladder exhibits no sensible pores, but if filled with water and suspended in the air, the water will gradually ooze through the walls of the bladder, and disappear by evaporation. Now, in its relation to the blood, the skin is such a bladder full of hot fluid.

Thus, perspiration to a certain amount must always be going on through the substance of the integument; but what the amount of this perspiration may be cannot be accurately ascertained, because a second and very important source of the perspiration is to be found in what are called the *sweat-glands.*

16. All over the body the integument presents minute apertures, the ends of channels excavated in the epidermis or scarf-skin, and each continuing the direction of a minute tube, usually about $\frac{1}{300}$th of an inch in diameter, and a quarter of an inch long, which is imbedded in the dermis. Each tube is lined with an epithelium continuous with the epidermis. The tube sometimes divides, but, whether single or branched, its inner end or ends are blind, and coiled up into a sort of knot, interlaced with a meshwork of capillaries (Fig. 28, A).

The blood in these capillaries is therefore separated from the cavity of the sweat-gland only by the thin walls of the capillaries, that of the glandular tube, and its epithelium, which, taken together, constitute but a very thin pellicle; and the arrangement, though different in detail, is similar in principle, to that which obtains in the kidney. In the latter, the vessel makes a coil within the Malpighian capsule, which ends a tubule. Here the perspiratory tubule coils about, and among, the vessels. In both cases the same result is arrived at—namely, the exposure of the blood to a large, relatively free, surface, on to which certain of its contents transude.

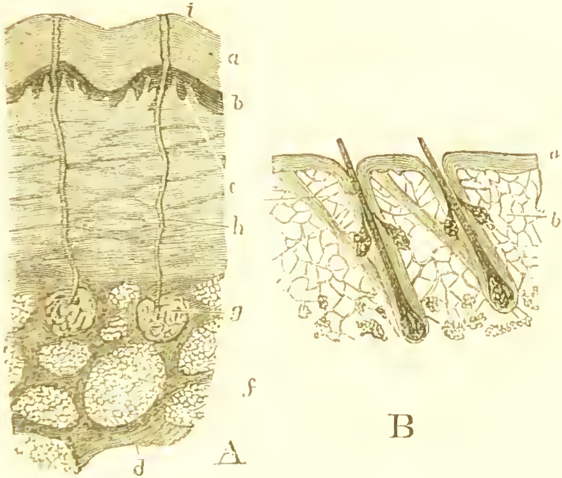

FIG. 28.

A Section of the skin showing the sweat-glands. *a*, the *epidermis*; *b*, its deeper layer, the *rete Malpighii*; *c d*, the *dermis*, or true skin; *f*, fat cells; *g*, the coiled end of a sweat gland; *h*, its duct; *i*, its opening on the surface of the epidermis. *B*. A section of the skin showing the roots of the hairs and the sebaceous glands; *b*, muscle of, *c*, the hair sheath on the left hand.

The number of these glands varies in different parts of the body. They are fewest in the back and neck, where their number is not much more than 400 to a square inch. They are more numerous on the skin of the palm and sole, where their apertures follow the ridges visible on the skin, and amount to between two and three thousand on the square inch. At a rough estimate, the whole integument probably possesses not fewer than from two millions and a quarter to two millions and a half of these tubules, which therefore must possess a very great aggregate secreting power.

17. The sweat-glands are greatly under the influence of the nervous system. This is proved, not merely by the well-known effects of mental emotion in sometimes suppressing the perspiration and sometimes causing it to be poured forth in immense abundance, but has been made a matter of direct experiment. There are some animals, such as the horse, which perspire very freely. If the sympathetic nerve of one side, in the neck of a horse, be cut, the same side of the head becomes injected with blood, and its temperature rises (see Lesson II. § 24); and, simultaneously, sweat is poured out abundantly over the whole surface thus affected. On irritating that end of the cut nerve which is in connexion with the vessels, the muscular walls of the latter, to which the nerve is distributed, contract, the congestion ceases, and with it the perspiration.

18. The amount of matter which may be lost by perspiration, under certain circumstances, is very remarkable. Heat and severe labour, combined, may reduce the weight of a man two or three pounds in an hour, by means of the cutaneous perspiration alone; and, as there is some reason to believe that the quantity of solid matter carried off from the blood does not diminish with the increase of the amount of the perspiration, the quantity even of urea which is eliminated by profuse sweating may be considerable.

The difference between blood which is coming from, and that which is going to, the skin, can only be concluded from the nature of the substances given out in the perspiration; but arterial blood is not rendered venous in the skin.

19. It will now be instructive to compare together in more detail than has been done in the First Lesson (Lesson I. § 23), the three great organs —lungs, kidneys, and skin—which have been described.

In ultimate anatomical analysis, each of these organs consists of a moist animal membrane separating the blood from the atmosphere.

Water, carbonic acid, and urea pass out from the blood through the animal membrane in each organ, and constitute its secretion or excretion; but the three organs differ in the absolute and relative amounts of the constituents the escape of which they permit.

Taken by weight, water is the predominant excretion in all three: most solid matter is given off by the kidneys; most gaseous matter by the lungs.

The skin partakes of the nature of both lungs and kidneys, seeing that it absorbs oxygen and exhales carbonic acid and water, like the former, while it excretes urea and saline matter in solution, like the latter; but the skin is more closely related to the kidneys than to the lungs. Hence when the free action of the skin is interrupted, its work is usually thrown upon the kidneys, and *vice versâ*. In hot weather, when the excretion by the skin increases, that of the kidneys diminishes, and the reverse is observed in cold weather.

This power of mutual substitution, however, only goes a little way; for if the kidneys be extirpated, or their functions much interfered with, death ensues, however active the skin may be. And, on the other hand, if the skin be covered with an impenetrable varnish, the temperature of the body rapidly falls, and death takes place, though the lungs and kidneys remain active.

20. The *liver* is a constant source both of loss, and, in a sense, of gain, to the blood which passes through it. It gives rise to loss, because it separates a peculiar fluid, the *bile*, from the blood, and throws that fluid into the intestine. It is a source of gain, if not in quantity, at any rate in kind, of matter, because it elaborates a substance, *glycogen*, which is capable of passing very readily into a kind of sugar, called *glucose*, and is carried off, in one shape or another, by the blood. Finally, it is very probable that the liver is one source of the colourless corpuscles of the blood.

The liver is the largest glandular organ in the body, ordinarily weighing about fifty or sixty ounces. It is a broad, dark, red-coloured organ, which lies on the right side of the body, immediately below the diaphragm, with which its upper surface is in contact, while its lower surface touches the intestines and the right kidney.

The liver is invested by a coat of peritoneum, which keeps it in place. It is flattened from above downwards, and convex and smooth above, where it fits into the concavity of the lower surface of the diaphragm. Flat and irregular below (Fig. 29), it is thick behind, but ends in a thin edge in front.

Viewed from below, as in Fig. 29, the *inferior vena cava*, *a*, is seen to traverse a notch in the hinder edge of the liver as it passes from the abdomen to the thorax. At *b* the trunk of the *vena portæ* is observed dividing into the chief branches

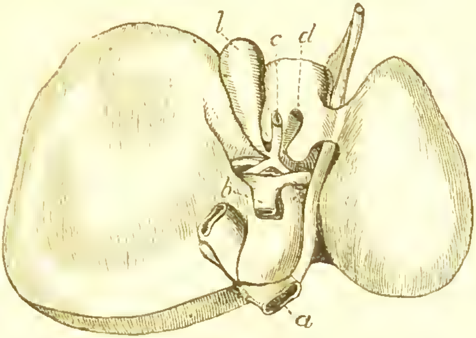

FIG. 29.

The liver viewed from below. *a*, vena cava; *b*, vena portæ; *c*, bile duct; *d*, hepatic artery; *l*, gall-bladder.

which enter into, and ramify through, the substance of the organ. At *d*, the *hepatic artery*, coming

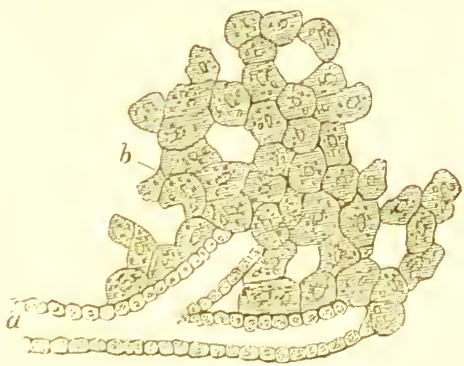

FIG. 30.

a, ultimate branches of the hepatic duct; *b*, liver cells.

almost directly from the aorta, similarly divides, enters the liver, and ramifies through it; while at *c* is the single trunk of the duct, called the *hepatic duct*, which conveys away the bile brought to it by its right and left branches from the liver. Opening

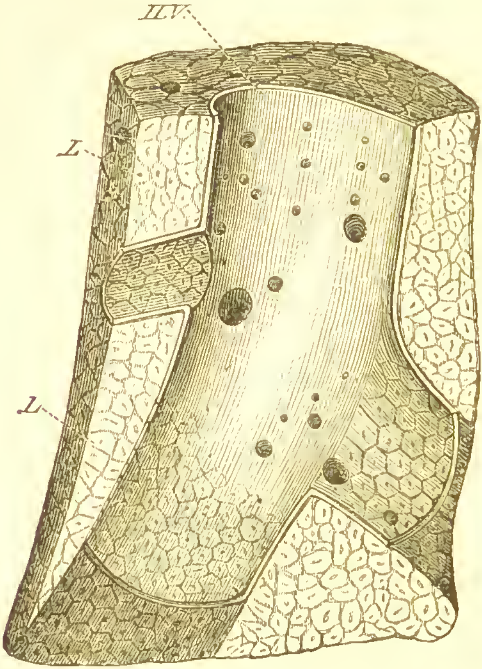

Fig. 31.

A section of part of the liver to show *H.V.* the hepatic vein, with *L.* the lobules or acini of the liver, seated upon its walls, and sending their intralobular veins into it.

into the hepatic duct is seen the duct of a large oval sac, *l*, the *gall-bladder*. The duct is smaller than the artery, and the artery than the portal vein.

If the branches of the artery, the portal vein, and the bile duct, be traced into the substance of the liver, they will be found to accompany one another, and to branch out and subdivide, becoming smaller and smaller. At length the portal vein and hepatic artery will be found to end in the capillaries, which traverse, like a network, the substance of the smallest obvious subdivisions of the liver substance—polygonal masses of one-tenth of an inch in diameter, or less, which are termed the *lobules*. Every *lobule* is seated by its base upon one of the ramifications of a great vein—the *hepatic vein*—and the blood of the capillaries of the lobule is poured into that vein by a minute veinlet, called *intralobular*, which traverses the centre of the lobule, and pierces its base. Thus the venous blood of the portal vein and the arterial blood of the hepatic artery reach the surfaces of the lobules by the ultimate ramifications of that vein and artery, become mixed in the capillaries of each lobule, and are carried off by its *intralobular* veinlet, which pours its contents into one of the ramifications of the hepatic vein. These ramifications, joining together, form larger and larger trunks, which at length reach the hinder margin of the liver, and finally open into the *vena cava inferior*, where it passes upwards in contact with that part of the organ.

Thus the blood with which the liver is supplied is a mixture of arterial and venous blood; the former brought by the hepatic artery directly from the aorta, the latter by the portal vein from the capillaries of the stomach, intestines, pancreas, and spleen.

What ultimately becomes of the ramifications of the hepatic duct is not certainly known. Lined by an epithelium, which is continuous with that of the main duct, and thence with that of the intestines, into which the main duct opens, they may be traced to the very surface of the lobules. Their ultimate ramifications are not yet thoroughly determined: but recent investigations tend to show that they communicate with minute passages left between the hepatic cells, and traversing the lobule in the intervals left by the capillaries. In either case, any fluid separated from the blood by the lobules must readily find its way into them.

In the lobules themselves all the meshes of the blood vessels are occupied by the liver cells. These are many-sided minute bodies, each about $\frac{1}{1000}$th of an inch in diameter, possessing a nucleus in its interior, and frequently having larger and smaller granules of fatty matter distributed through its substance (Fig. 30, *b*). It is in the liver cells that the active powers of the liver are supposed to reside.

21. The nature of these active powers, so far as the liver is a source of loss to the blood which traverses it, is determined by ascertaining—

a. The character of that fluid, the bile, which incessantly flows down the biliary duct, and which, if digestion is not going on, and the passage into the intestine is closed, flows back into and fills the gall-bladder.

b. The difference between the blood which enters the liver and that which leaves it in respect of the constituents of the bile.

22. *a.* The total quantity of bile secreted in the twenty-four hours varies, but probably amounts to not less than from two to three pounds. It is a greenish yellow, slightly alkaline, fluid, of extremely bitter taste, consisting of water, with from 17 per cent. to half that quantity, of solid matter in solution. The solids consist chiefly of a resinous substance, com-

posed of carbon, hydrogen, oxygen, nitrogen, and sulphur, which exists in combination with soda. This biliary matter, or *bilin*, may be separated by chemical processes into two acids, called the *Taurocholic* (which contains all the sulphur) and the *Glycocholic;* and it is consequently said to be a combination of *taurocholate* and *glycocholate* of soda. Besides this bilin, its chief constituent, the bile contains a crystallized fatty substance, *cholesterine*, together with a peculiar colouring matter which contains iron, and is probably related to the hæmatin of the blood.

b. Of these constituents of the bile the water, the cholesterine, and the saline matters, alone, are discoverable in the blood; and, though doubtless some difference obtains between the blood which enters the liver and that which leaves it, in respect of the proportional quantity of these constituents, great practical difficulties lie in the way of the precise ascertainment of the amount of that difference. The blood of the hepatic vein, however, is certainly poorer in water than that of the portal vein.

23. As the essential constituent of bile, *bilin*, is not discoverable in the blood which enters the liver, it must be formed at the expense of the tissue of that organ itself, or of some constituent of the blood passing through it. However this may be, it is a very curious circumstance that, as almost all the bile which is poured into the intestines is re-absorbed by the vessels in their walls, it must, in some shape or other, enter the liver a second time with the current of the portal blood.

24. We must next consider the chief sources of constant gain to the blood; and, in the first place, *the sources of gain of matter.*

The lungs and skin are, as has been seen, two of the principal channels by which the body loses liquid and gaseous matter, but they are also the sole means by which one of the most important of all substances for the maintenance of life, *oxygen*, is introduced into the blood. It has already been pointed out that the volume of the oxygen taken into the blood by the lungs is rather greater than that of the carbonic acid given out. The absolute weight of oxygen thus absorbed may be estimated at 10,000 grains (see Lesson VI. § 2).

How much is taken in by the skin of man is not certainly known, but in some of the lower animals, such as the frog, the skin plays a very important part in the performance of the respiratory function.

25. The blood leaving the liver by the hepatic vein, not only contains proportionally less water and fibrin, but proportionally more corpuscles, especially colourless corpuscles, and, what is still more important, a larger quantity of liver-sugar, or *glucose*, than that brought to it by the portal veins and hepatic artery ; and these differences are irrespective of the nature of the food.

That the blood leaving the liver should contain proportionally less water and more corpuscles than that entering it, is no more than might be expected from the fact that the formation of the bile, which is separated from this blood, necessarily involves a loss of water and of some solid matters, while it does not abstract any of the corpuscles.

We do not know why less fibrin separates from the blood of the hepatic vein than from the blood brought to the liver. But the reason why there is always more sugar in the blood leaving the liver than in that entering it; and why, in fact, there is plenty of sugar in the blood of the hepatic vein even when none whatever is brought to it by the hepatic artery, or portal vein; has only been made out by careful and ingenious experimental research within the last few years.

26. If an animal be fed upon purely animal food, the blood of the portal vein will contain no sugar, none having been absorbed by the walls of the alimentary canal, nor will that of the hepatic artery contain any, or, at any rate, more than the merest trace. Nevertheless, plenty will be found, at the same time, in the blood of the hepatic vein and in that of the vena cava, from the point at which it is joined by the hepatic vein, as far as the heart.

Secondly, if, from an animal so fed, the liver be extracted, and a current of cold water forced into the *vena portæ,* it will flow out by the hepatic vein, carrying with it all the blood of the organ, and will, after a time, pour out colourless, and devoid of sugar. Nevertheless, if the organ be left to itself at a moderate temperature, sugar will soon again become abundant in it.

Thirdly, from the liver, washed as above described, a substance may be extracted, by appropriate methods, which resembles starch, dextrine, and gum in chemical composition, consisting as it does of carbon united with hydrogen and oxygen, the latter being in the same proportions as in water. This "amyloid" substance is the *glycogen* spoken of in § 20. It may be dried and kept for long periods without undergoing any change.

But, like the vegetable starch and dextrine, this animal amyloid, which must be formed in the liver, since it is certainly not contained either in the blood of the portal vein, or in that of the hepatic artery, is very readily changed by contact with certain matters, which act as ferments, into sugar.

Fourthly, it may be demonstrated that a ferment, competent to change the "amyloid" glycogen into saccharine "*glucose*," exists under ordinary circumstances in the liver.

Putting all these circumstances together, the following explanation of the riddle of the appearance of sugar in the blood of the hepatic vein and vena cava, when neither it, nor any compound out of which it is easily formed, exists in the blood brought to the liver, appears to have much probability; though it may possibly require modification, in some respects, hereafter.

The liver forms glycogen out of the blood with which it is supplied. The same blood supplies the ferment which, at the temperature of the body, very speedily converts the comparatively little soluble glycogen into very soluble sugar; and this sugar is dissolved and carried away by each intralobular vein to the hepatic vein, and thence to the vena cava.

27. The *lymphatic system* has been already mentioned as a feeder of the blood with a fluid which, in general, appears to be merely the superfluous drainage, as it were, of the blood-vessels; though at intervals, as we shall see, the lacteals make substantial additions of new matter. It is very probable that the multitudinous *lymphatic glands* may effect some change in the fluid which traverses them, or may add to the number of corpuscles in the lymph.

The glandular bodies, which, like the lymphatic glands, are devoid of ducts, and are abundantly supplied with lymphatics, are the *thyroid* gland, which lies in the part of the throat below the larynx, and is that organ which, when enlarged by disease, gives rise to "Derbyshire neck" or "goitre:" the *thymus* gland, situated at the base of the heart, largest in infants, and gradually disappearing in adult and old persons: and the *supra-renal* capsules, which lie above the kidneys. Nothing *certain* is known of the functions of any of these bodies.

28. We are as much in the dark respecting the office of the large viscus called the *spleen*, which lies upon the left side of the stomach in the abdominal cavity (Fig. 32). It is an elongated flattened red body, abundantly supplied with blood by an artery called the *splenic artery*, which proceeds almost directly from the aorta. The blood which has traversed the spleen is collected by the *splenic vein*, and is carried by it to the *vena portæ*, and so to the liver.

A section of the spleen shows a dark red spongy mass dotted over with minute whitish spots. Each of these last is the section of one of the spheroidal bodies called *corpuscles of the spleen*, which are scattered through its substance, and consist of a solid aggregation of minute bodies, like the white corpuscles of the blood, traversed by a capillary network, which is fed by a small twig of the splenic artery. The dark red part of the spleen, in which these corpuscles are embedded, is composed of fibrous and elastic tissue supporting a very spongy vascular network.

The elasticity of the splenic tissue allows the organ to be readily distended, and enables it to return to its former size after distension. It appears to change its dimensions with the state of the abdominal viscera, attaining its largest size about six hours after a full meal, and falling to its minimum bulk six or seven hours later, if no further supply of food be taken.

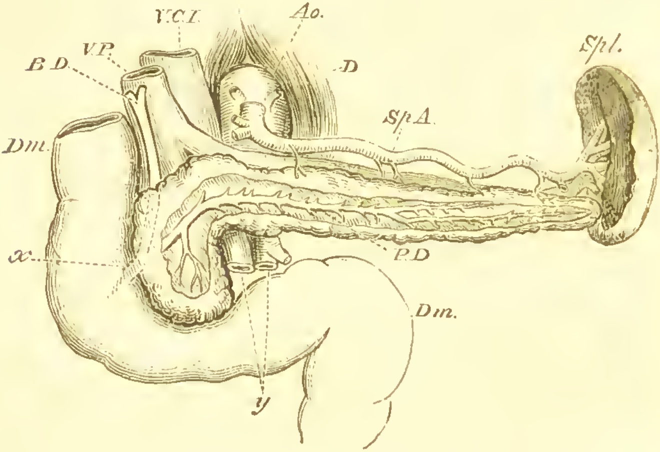

Fig. 32.

The spleen (*Spl.*) with the splenic artery (*SpA.*). Below this is seen the splenic vein running to help to form the *vena portæ* (*V.P.*). *Ao.* the aorta; *D.* a pillar of the diaphragm; *P.D.* the pancreatic duct exposed by dissection in the substance of the pancreas; *Dm.* the duodenum; *B.D.* the biliary duct uniting with the pancreatic duct into the common duct, *x*; *y*, the intestinal vessels.

The blood of the splenic vein is found to contain proportionally fewer red corpuscles, but more colourless corpuscles and more fibrin, than that in the splenic artery; and it has been supposed that the spleen is one of those parts of the economy in which the colourless corpuscles of the blood are especially produced.

29. It has been seen that *heat* is being constantly given off from the integument and from the air-passages; and everything that passes from the body carries away with it, in like manner, a certain quantity of heat. Furthermore, the surface of the body is much more exposed to cold than its interior. Nevertheless, the temperature of the body is maintained very evenly, at all times and in all parts, within the range of two degrees on either side of 99° Fahrenheit.

This is the result of three conditions:—The first, that heat is constantly being generated in the body. The second, that it is as constantly being distributed through the body. The third, that it is subject to incessant regulation.

Heat is generated whenever oxidation takes place; and hence, whenever protein substances, or fats, or amyloidal matters, are being converted into the more highly oxidated waste products,—urea, uric acid, carbonic acid, and water,—heat is necessarily evolved. But these processes are taking place in all parts of the body by which vital activity is manifested; and hence every capillary vessel and every extravascular islet of tissue is really a small fireplace in which heat is being evolved, in proportion to the activity of the chemical changes which are going on.

30. But as the vital activities of different parts of the body, and of the whole body, at different times, are very different; and as some parts of the body are so situated as to lose their heat by radiation and conduction much more easily than others, the temperature of the body would be very unequal in its different parts and at different times, were it not for the arrangements by which the heat is distributed and regulated.

Whatever oxidation occurs in any part, raises the temperature of the blood which is in that part at the time to a proportional extent. But this blood is swiftly hurried away into other regions of the body, and rapidly gives up its increased temperature to them. On the other hand, the blood of the surface of the body, the temperature of which is lowered by evaporation and radiation, suffers only a very slight loss of heat before it is transported into the deeper organs; and in them it becomes warmed by contact, as well as by the oxidating processes in which it takes a part. Thus the blood-vessels and their contents might be compared to a system of hot-water pipes, through which the warm water is kept constantly circulating by a pump; while it is heated, not by a great central boiler as usual, but by a multitude of minute gas jets, disposed beneath the pipes, not evenly, but more here and fewer there. It is obvious that, however much greater might be the heat applied to one part of the system of pipes than to another, the general temperature of the water would be even throughout, if it were kept moving with sufficient quickness by the pump.

31. If such a system were entirely composed of closed pipes, the temperature of the water might be raised to any extent by the gas jets. On the other hand, it might be kept down to any required degree by causing a larger, or smaller, portion of the pipes to be wetted with water, which should be able to evaporate freely—as, for example, by wrapping them in wet cloths. And the greater the quantity of water thus evaporated, the lower would be the temperature of the whole apparatus.

Now the regulation of the temperature of the human body is effected on this principle. The vessels are closed pipes, but a great number of them are enclosed in the skin and in the mucous membrane of the air-passages, which are, in a physical sense, wet cloths freely exposed to the air. It is the evaporation from these which exercises a more important influence than any other condition upon the regulation of the temperature of the blood, and consequently of the body.

But, as a further nicety of adjustment, the wetness of the regulator is itself determined by the state of the small vessels, inasmuch as exudation from these takes place more readily when the walls of the veins and arteries are relaxed, and the blood distends them and the capillaries. But the condition of the walls of the vessels depends upon the nerves by which they are supplied, and it so happens that cold so affects these nerves in such a manner as to give rise to contraction of the small vessels; while moderate warmth has the reverse effect.

Thus the supply of blood to the surface is lessened, and loss of heat is thereby checked, when the external temperature is low; while, when the external temperature is high, the supply of blood to the surface is increased, the fluid exuded from the vessels pours out by the sweat glands, and the evaporation of this fluid checks the rise in the temperature of the superficial blood.

Hence it is that, so long as the surface of the body perspires freely, and the air-passages are abundantly moist, a man may remain with impunity, for a considerable time, in an oven in which meat is being cooked. The heat of the air is expended in converting this superabundant perspiration into vapour, and the temperature of the man's blood is hardly raised.

32. The chief *intermittently active sources of loss* to the blood are found among the *glands* proper, all of which are, in principle, narrow pouches of the mucous membranes, or of the integument of the body, lined by a continuation of the epithelium or of the epidermis. In the *glands of Lieberkühn*, which exist in immense numbers in the walls of the small intestines, each gland is nothing more than a simple blind sac of the mucous membrane, shaped like a small test tube, with its closed end outwards, and its open end on the inner surface of the intestine.

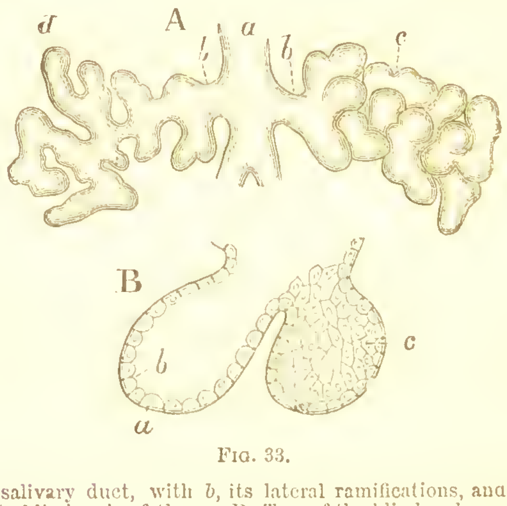

FIG. 33.

a, a salivary duct, with *b*, its lateral ramifications, and *d*, the ultimate blind ends of these. B. Two of the blind ends magnified.

The sweat-glands of the skin, as we have already seen, are equally simple, blind, tube-like involutions of the integument, the ends of which become coiled up. The *sebaceous glands*, usually connected with the hair sacs, are shorter, and their blind ends are somewhat subdivided, so that the gland is divided into a narrow neck and a more dilated and sacculated end. The neck by which the gland communicates with the free surface is called its *duct.* More complicated glands are produced by the elongation of the duct into a long tube, and the division and subdivision of the blind end into multitudes of similar tubes, each of which ends in a dilatation. These dilatations, attached to their branched ducts, somewhat resemble a bunch of grapes. Glands of this kind are called *racemose.* The *salivary glands* and the *pancreas* are such glands.

Now, many of these glands, such as the salivary, and the pancreas (with the perspiratory, or sudoriparous glands, which it has been convenient to consider already), are only active when certain impressions on the nervous system give rise to a particular condition of the gland, or of its vessels, or of both.

Thus the sight or smell, or even the thought of food, will cause a flow of saliva into the mouth; the previously quiescent gland suddenly pouring out its fluid secretion, as a result of a change in the condition of the nervous system. And, in animals, the salivary glands can be made to secrete abundantly, by irritating a nerve which supplies the gland and its vessels. How far this effect is the result of the mechanical influence of the nerve on the state of the circulation, and how far it is the result of a more direct influence of the nerve upon the state of the tissue of the gland itself, is not at present determined.

The liquids poured out by the intermittent glands are always very poor in solid constituents, and consist chiefly of water. Those poured on to the surface of the body are lost, but those which are received by the alimentary canal are doubtless in a great measure re-absorbed.

33. The great *intermittent sources of gain of waste products* to the blood are the muscles, every contraction of which is accompanied by an oxidation of matter, and a pouring of the oxidated products into the blood. That much of this waste is carbonic acid is certain from the facts (*a*) that the blood which leaves a contracting muscle is always highly venous, far more so than that which leaves a quiescent muscle; and (*b*) that muscular exertion at once immensely increases the quantity of carbonic acid expired: but whether the amount of nitrogenous waste is increased under these circumstances or not, is a point yet under discussion.

LESSON VI.

THE FUNCTION OF ALIMENTATION

1. The great source of gain to the blood, and, except the lungs, the only channel by which altogether new material is introduced into that fluid, is the *alimentary canal*, the totality of the operations of which constitutes the function of *alimentation*. It will be useful to consider the general nature and results of the performance of this function before studying its details.

2. A man daily takes into his mouth, and thereby introduces into his alimentary canal, a certain quantity of solid and liquid food, in the shape of meat, bread, butter, water, and the like. The amount of chemically dry, solid matter, which must thus be taken into the body, if a man of average size and activity is neither to lose, nor to gain, in weight, has been found to be about 8,000 grains. In addition to this his blood absorbs by the lungs about 10,000 grains of oxygen gas, making a grand total of 18,000 grains (or nearly two pounds and three-quarters avoirdupois) of daily gain of dry solid and gaseous matter.

3. The weight of dry solid matter passed out from the alimentary canal does not, on the average, amount to more than one-tenth of that which is taken into it, or 800 grains. By no other channel does any appreciable quantity of solid matter leave the body. It follows, therefore, that in addition to the 10,000 grains of oxygen, 7,200 grains of dry

solid matter must pass out of the body in the other, or gaseous and liquid secretions. Further, as the general composition of the body remains constant, it follows either that the elementary constituents of the solids taken into the body must be identical with those of the body itself: or that, in the course of the vital processes, the food alone is destroyed, the substance of the body remaining unchanged: or, finally, that both these alternatives hold good, and that food is, partly, identical with the wasting substance of the body and replaces it; and, partly, differs from the wasting substance, and is consumed without replacing it.

4. As a matter of fact, all the substances which are used as food come under one of four heads. They are either what may be termed *Proteids*, or they are *Fats*, or they are *Amyloids*, or they are *Minerals*.

Proteids are substances analogous in composition to *Protein*, and contain the four elements—carbon, hydrogen, oxygen, and nitrogen, sometimes united with sulphur and phosphorus.

Under this head come the *Gluten* of flour; the *Albumen* of white of egg, and of blood serum; the *Fibrin* of the blood; the *Syntonin*, which is the chief constituent of muscle and flesh, and *Casein*, the chief constituent of cheese; while *Gelatin*, which is obtained by boiling from connective tissue, and *Chondrin*, which may be produced in the same way from cartilage, may be considered to be outlying members of the same group.

Fats are composed of carbon, hydrogen, and oxygen only, and contain more hydrogen than is enough to form water if united with the oxygen which they possess.

All oils and vegetable and animal fatty matters come under this division.

Amyloids are substances which also consist of carbon, hydrogen, and oxygen only. But they contain no more hydrogen than is just sufficient to produce water with their oxygen. These are the matters known as *Starch*, *Dextrine*, *Sugar*, and *Gum*.

It is the peculiarity of the three groups of food-stuffs just mentioned that they can only be obtained (at any rate, at present) by the activity of living beings, whether animals or plants, so that they may be conveniently termed *vital food-stuffs*.

Food-stuffs of the fourth class, on the other hand, or *Minerals*, are to be procured as well from the not-living, as the living, world. They are *water*, and *salts* of sundry alkalies, earths, and metals. To these, in strictness, *oxygen* ought to be added, though, as it is not taken in by the alimentary canal, it hardly comes within the ordinary acceptation of the word food.

5. In ultimate analysis, then, it appears that *vital food-stuffs* contain either three or four of the elements: carbon, hydrogen, oxygen, and nitrogen; that *mineral food-stuffs* are water and salts. But the human body, in ultimate analysis, also proves to be composed of the same four elements, *plus* water, and the same saline matters as are found in food.

More than this, no substance can serve permanently for food—that is to say, can prevent loss of weight and change in the general composition of the body—unless it contains a certain amount of protein in the shape of albumen, fibrin, syntonin, or casein. While, on the other hand, any substance which contains protein in a readily assimilable shape, is competent to act as a permanent vital food-stuff.

The human body, as we have seen, contains a large quantity of protein in one or other of the four forms which have been enumerated; and, therefore, it turns out to be an indispensable condition, that every substance which is to serve permanently as food, must contain a sufficient quantity of the most important and complex component of the body ready made. It must also contain a sufficient quantity of the mineral ingredients which are required. Whether it contains either fats or amyloids, or both, or is devoid of both, its essential power of supporting the life and maintaining the weight and composition of the body remains unchanged.

6. The necessity of constantly renewing the supply of protein arises from the circumstance that the secretion of urea from the body (and consequently the loss of nitrogen) goes on continually, whether the body is fed or not: while there is only one form in which nitrogen (at any rate, in any considerable quantity) can be taken into the blood, and that is in the form of a solution of protein. If protein be not supplied, therefore, the body must needs waste, because there is nothing in the food competent to make good the loss of nitrogen.

On the other hand, if protein be supplied, there can be no *absolute* necessity for any other but the mineral food-stuffs, because protein contains carbon and hydrogen in abundance, and hence is competent to give origin to the other great products of waste, carbonic acid and water.

In fact, the final results of the oxidation of protein are carbonic acid, water, and ammonia; and these, as we have seen, are the final shapes of the waste products of the human economy.

7. From what has been said, it becomes readily intelligible that, whether an animal be herbivorous or carnivorous, it begins to starve from the moment its vital food-stuffs consist of pure amyloids, or fats, or any mixture of them. It suffers from what may be called *nitrogen starvation*, and, sooner or later, will die.

In this case, and still more in that of an animal deprived of vital food altogether, the organism, so long as it continues to live, feeds upon itself. In the former case, those excretions which contain nitrogen, in the latter, all its waste products, are necessarily formed at the expense of its own body; whence it has been rightly enough observed that a starving sheep is as much a carnivore as a lion.

8. But though protein is the essential element of food, and under certain circumstances may suffice, by itself, to maintain the body, it is a very disadvantageous and uneconomical food.

Albumen, which may be taken as the type of the proteids, contains about 53 parts of carbon and 15 of nitrogen in 100 parts. If a man were to be fed upon white of egg, therefore, he would take in, speaking roughly, $3\frac{1}{2}$ parts of carbon for every part of nitrogen.

But it is proved experimentally, that a healthy full-grown man, keeping up his weight and heat, and taking a fair amount of exercise, eliminates 4,000 grains of carbon to only 300 grains of nitrogen, or, roughly, only needs one-thirteenth as much nitrogen as carbon. However, if he is to get his 4,000 grains of carbon out of albumen, he must eat 7,547 grains of that substance. But

7,547 grains of albumen contain 1,132 grains of nitrogen, or nearly four times as much as he wants.

To put the case in another way, it takes about four pounds of fatless meat (which generally contains about one-fourth its weight of dry proteids), to yield 4,000 grains of carbon, whereas one pound will furnish 300 grains of nitrogen.

Thus a man confined to a purely proteid diet, must eat a prodigious quantity of it. This not only involves a great amount of physiological labour in comminuting the food, and a great expenditure of power and time in dissolving and absorbing it; but throws a great quantity of wholly profitless labour upon those excretory organs, which have to get rid of the nitrogenous matter, three-fourths of which, as we have seen, is superfluous.

Unproductive labour is as much to be avoided in physiological, as in political, economy; and it is quite possible that an animal fed with perfectly nutritious protein matter should die of starvation, the loss of power in the various operations required for its assimilation overbalancing the gain; or the time occupied in their performance being too great to check waste with sufficient rapidity. The body, under these circumstances, falls into the condition of a merchant who has abundant assets, but who cannot get in his debts in time to meet his creditors.

9. These considerations lead us to the physiological justification of the universal practice of mankind in adopting a mixed diet, in which proteids are mixed either with fats, or with amyloids, or with both.

Fats may be taken to contain about 80 per cent. of carbon, and amyloids about 40 per cent. Now it has been seen that there is enough nitrogen to supply the waste of that substance per diem, in a healthy man, in a pound of fatless meat; which also contains 1,000 grains of carbon, leaving a deficit of 3,000 grains of carbon. Rather more than half a pound of fat, or a pound of sugar, will supply this quantity of carbon. The former, if properly subdivided, the latter, by reason of its solubility, passes with great ease into the economy, the digestive labour of which is consequently reduced to a minimum.

10. Several apparently simple articles of food constitute a mixed diet in themselves. Thus butcher's meat commonly contains from 30 to 50 per cent. of fat. Bread, on the other hand, contains the proteid, gluten, and the amyloids, starch and sugar, with minute quantities of fat. But, from the proportion in which these proteid and other constituents exist in these substances, they are neither, taken alone, such physiologically economical foods as they are when combined in the proportion of about 200 to 75; or two pounds of bread to three-quarters of a pound of meat per diem.

11. It is quite certain that nine-tenths of the dry solid food which is taken into the body, sooner or later leaves it in the shape of carbonic acid, water, and urea (or uric acid); and it is also certain that, as the compounds which leave the body are more highly oxidated than those which enter it, and as free oxygen is nowhere eliminated, all the oxygen taken in by the lungs passes away in these compounds.

The intermediate stages of this conversion are, however, by no means so clear. It is highly probable that the amyloids and fats are very frequently oxidated in the blood, without, properly speaking, ever forming an integral part of the substance of the body; but whether the proteids may undergo the same changes in the blood, or whether it is necessary for them first to be incorporated with the living tissue, is not positively known.

So, again, it is certain that, in becoming oxidated, the elements of the food must give off heat, and it is probable that this heat is sufficient to account for all that is given off by the body; but it is possible, and indeed probable, that there may be other, minor, sources of heat.

12. Food-stuffs have been divided into *heat-producers* and *tissue-formers*—the amyloids and fats constituting the former division, the proteids the latter. But this is a very misleading classification, inasmuch as it implies, on the one hand, that the oxidation of the proteids does not develop heat; and, on the other, that the amyloids and fats, as they oxidize, subserve only the production of heat.

Proteids are *tissue-formers*, inasmuch as no tissue can be produced without them; but they are also *heat-producers*, not only directly, but because, as we have seen (Lesson V. §§ 25, 26), that they are competent to give rise to amyloids by chemical metamorphosis within the body.

If it is worth while to make a special classification of the vital food-stuffs at all, it appears desirable to distinguish the *essential* food-stuffs, or proteids, from the *accessory* food-stuffs, or fats and amyloids—the former alone being, in the nature of things, necessary to life, while the latter, however important, are not absolutely necessary.

13. All food-stuffs being thus proteids, fats, amyloids, or mineral matters, pure or mixed up

with other substances, the whole purpose of the alimentary apparatus is to separate these proteids, &c. from the innutritious residue, if there be any; and to reduce them into a condition either of solution or of excessively fine subdivision, in order that they may make their way through the delicate structures which form the walls of the vessels of the alimentary canal. To these ends food is taken into the mouth and masticated, is insalivated, is swallowed, undergoes gastric digestion, passes into the intestine, and is subjected to the action of the secretions of the glands attached to that viscus; and, finally, after the more or less complete extraction of the nutritive constituents, the residue, mixed up with certain secretions of the intestines, leaves the body as the *fæces*.

The cavity of the mouth is a chamber with a fixed roof, formed by the hard *palate* (Fig. 34, *l*), and with a moveable floor, constituted by the lower jaw, and the tongue (*k*), which fills up the space between the two branches of the jaw. Arching round the margins of the upper and the lower jaws are the thirty-two teeth, sixteen above and sixteen below, and, external to these, the closure of the cavity of the mouth is completed by the cheeks, at the sides, and by the lips, in front.

When the mouth is shut, the back of the tongue comes into close contact with the palate; and, where the hard palate ends, the communication between the mouth and the back of the throat is still further impeded by a sort of fleshy curtain—the soft *palate*, or *velum*—the middle of which is produced into a prolongation, the *uvula* (*f*), while its sides, skirting the sides of the passage, or *fauces*, form double muscular pillars, which are termed the *pillars of the fauces.* Between these the *tonsils* are situated, one on each side.

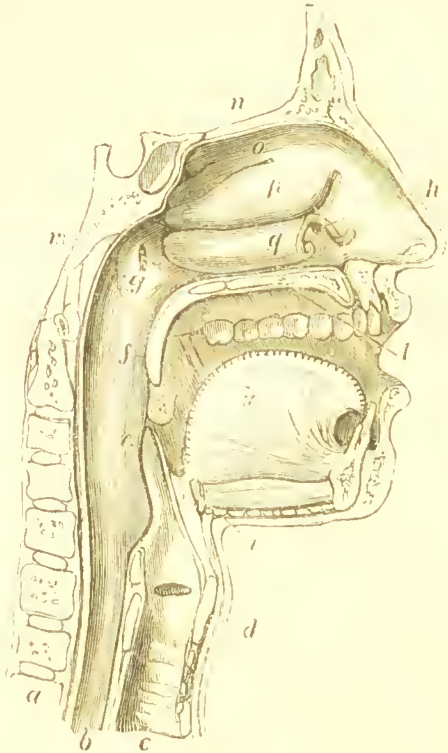

FIG. 34.

A section of the mouth and nose, taken vertically a little to the left of the middle line. *a*, the vertebral column; *b*, the gullet; *c*, the windpipe; *d*, the thyroid cartilage of the larynx; *e*, the epiglottis; *f*, the uvula; *g*, the opening of the left Eustachian tube; *h*, the opening of the left lachrymal duct; *i*, the hyoid bone; *k*, the tongue; *l*, the hard palate; *m n*, the base of the skull; *o p q*, the superior, middle, and inferior turbinal bones. The letters *g f e* are placed in the pharynx.

The velum with its uvula comes into contact below with the upper part of the back of the tongue, and with a sort of gristly, lid-like process connected with its base, the *epiglottis* (*e*).

Behind the partition thus formed lies the cavity of the *pharynx*, which may be described as a funnel-shaped bag with muscular walls, the upper margins of the slanting wide end of which are attached to the base of the skull, while its lateral margins are continuous with the sides, and its lower wall with the floor, of the mouth. The narrow end of the pharyngeal bag passes into the gullet or œsophagus (*b*), a muscular tube, which affords a passage into the stomach.

There are no fewer than six distinct openings into the front part of the pharynx—four in pairs, and two single ones in the middle line. The two pairs are, in front, the hinder openings of the nasal cavities; and at the sides, close to these, the apertures of the *Eustachian tubes* (*g*). The two single apertures are, the hinder opening of the mouth between the soft palate and the epiglottis; and, behind the epiglottis, the upper aperture of the respiratory passage, or the *glottis*.

14. The mucous membrane which lines the mouth and the pharynx is beset with minute glands, the *buccal glands;* but the great glands from which the cavity of the mouth receives its chief secretion are the three pairs which, as has been already mentioned, are called *parotid*, *submaxillary*, *sublingual*, and which secrete the principal part of the saliva. (Fig. 35.)

Each parotid gland is placed just in front of the ear, and its duct passes forwards along the cheek, until it opens in the interior of the mouth, opposite the second upper grinding tooth.

The submaxillary and sublingual glands lie between the lower jaw and the floor of the mouth, the submaxillary being situated further back than the sublingual. Their ducts open in the floor of the mouth below the tip of the tongue. The secretion of these salivary glands, mixed with that of the small glands of the mouth, constitutes the *saliva*—a fluid which, though thin and watery, contains a small quantity of animal matter, called *Ptyalin*, which has certain very peculiar properties. It does

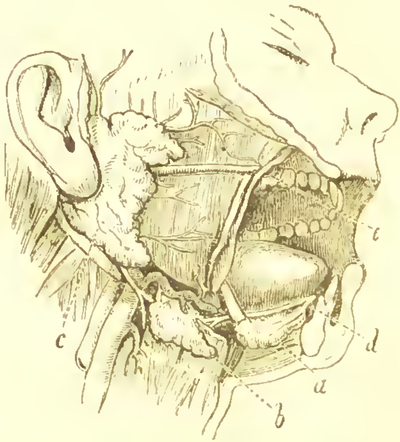

FIG 35.

A dissection of the right side of the face, showing *a*, the sublingual; *b*, the submaxillary glands, with their ducts opening beside the tongue in the floor of the mouth at *d*; *c*, the parotid gland and its duct, which opens on the side of the cheek at *e*.

not act upon proteid food-stuffs, nor upon fats; but if mixed with starch, and kept at a moderate warm temperature, it turns that starch into grape sugar. The importance of this operation becomes apparent when one reflects that starch is insoluble and useless as nutriment, while sugar is highly soluble, and readily oxidable.

15. Each of the thirty-two teeth which have been mentioned consists of a *crown* which projects above the gum, and of one or more *fangs*, which are embedded in sockets, or what are called *alveoli*, in the jaws.

The eight teeth on opposite sides of the same jaw are constructed upon exactly similar patterns, while the eight teeth which are opposite to one another, and bite against one another above and below, though similar in kind, differ somewhat in the details of their patterns.

The two teeth in each eight which are nearest the middle line in the front of the jaw, have wide but sharp and chisel-like edges. Hence they are called *incisors*, or cutting teeth. The tooth which comes next is a tooth with a more conical and pointed crown. It answers to the great tearing and holding tooth of the dog, and is called the *canine* or eye tooth. The next two teeth have broader crowns, with two cusps, or points, on each crown, one on the inside and one on the outside, whence they are termed *bicuspid* teeth, and sometimes false grinders. All these teeth have usually one fang each, except the bicuspid, the fang of which may be more or less completely divided into two. The remaining teeth have two or three fangs each, and their crowns are much broader. As they crush and grind the matters which pass between them they are called *molars*, or true grinders. In the upper jaw their crowns present four points at the four corners and a diagonal ridge connecting two of them. In the lower jaw the complete pattern is five-pointed, there being two cusps on the inner side and three on the outer.

The muscles of the parts which have been described have such a disposition that the lower jaw can be depressed, so as to open the mouth and separate the teeth ; or raised, in such a manner as to bring the teeth together ; or moved obliquely from side to side, so as to cause the face of the grinding teeth and the edges of the cutting teeth to slide over one another. And the muscles which perform the elevating and sliding movements are of great strength, and confer a corresponding force upon the grinding and cutting actions of the teeth. In correspondence with the pressure they have to resist, the superficial substance of the crown of the teeth is of great hardness, being formed of *enamel*, which is the hardest substance in the body, so dense and hard, indeed, that it will strike fire with steel (see Lesson XII.). But notwithstanding its extreme hardness, it becomes worn down in old persons, and at an earlier age, in savages who live on coarse food.

16. When solid food is taken into the mouth, it is cut and ground by the teeth, the fragments which ooze out upon the outer side of their crowns being pushed beneath them again by the muscular contractions of the cheeks and lips ; while those which escape on the inner side are thrust back by the tongue, until the whole is thoroughly rubbed down.

While mastication is proceeding, the salivary glands pour out their secretion in great abundance, and the saliva mixes with the food, which thus becomes interpenetrated not only with the salivary fluid, but with the air which is entangled in the bubbles of the saliva.

When the food is sufficiently ground it is collected, enveloped in saliva, into a mass or bolus, which rests upon the back of the tongue, and is carried backwards to the aperture which leads into the pharynx. Through this it is thrust, the soft palate being lifted and its pillars being brought together, while the backward movement of the tongue at once propels the mass and causes the epiglottis to incline backwards and downwards over the glottis, and so to form a bridge by which the bolus can travel over the opening of the air-passage without any risk of tumbling into it. While the epiglottis directs the course of the mass of food below, and prevents it from passing into the trachea, the soft palate guides it above, keeps it out of the nasal chamber, and directs it downwards and backwards towards the lower part of the muscular pharyngeal funnel. By this the bolus is immediately seized and tightly held, and the muscular fibres contracting above it, while they are comparatively lax below, it is rapidly thrust into the œsophagus. By the muscular walls of this tube it is grasped and propelled onwards, in a similar fashion, until it reaches the stomach.

17. Drink is taken in exactly the same way. It does not fall down the pharynx and gullet, but each gulp is grasped and passed down. Hence it is that jugglers are able to drink standing upon their heads, and that a horse, or ox, drinks with its throat lower than its stomach, feats which would be impossible if fluid simply fell down the gullet into the gastric cavity.

During these processes of mastication, insalivation, and deglutition, what happens to the food is, first, that it is reduced to a coarser or finer pulp; secondly, that any matters it carries in solution are still more diluted by the water of the saliva; thirdly, that any starch it may contain begins to be changed into sugar by the peculiar constituent (ptyalin) of the saliva.

18. The stomach, like the gullet, consists of a tube with muscular walls composed of smooth muscular fibres, and lined by an epithelium; but it differs from the gullet in several circumstances. In the first place, its cavity is greatly larger, and its left end is produced into an enlargement which, because it

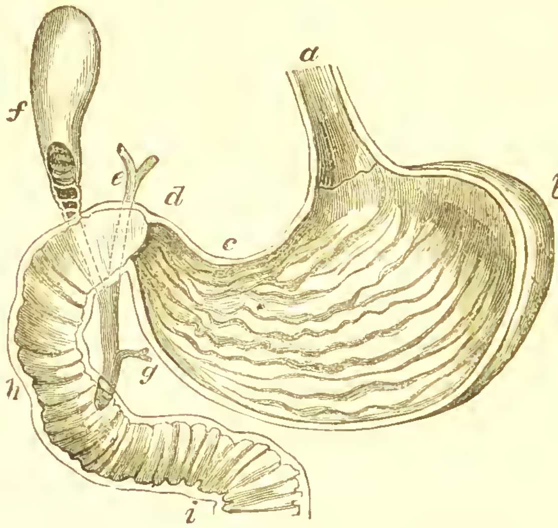

FIG. 36.

The stomach laid open behind.—*a*, the œsophagus; *b*, the cardiac dilatation; *c*, the lesser curvature; *d*, the pylorus; *e*, the biliary duct; *f*, the gall-bladder; *g*, the pancreatic duct, entering the common duct which opens opposite *h*; *h i*, the duodenum.

is on the heart side of the body, is called the *cardiac* dilatation (Fig. 36, *b*). The opening of the gullet into the stomach, termed the *cardiac aperture*, is consequently nearly in the middle of the whole length of the organ, which presents a long, convex, *greater curvature*, along its front or under edge, and a short concave, *lesser curvature*, on its back or upper contour. Towards its right extremity the stomach narrows and, where it passes into the intestine, the muscular fibres are so disposed as to form a sort of sphincter around the aperture of communication. This is called the *pylorus* (Fig. 36, *d*).

The mucous membrane lining the wall of the stomach is very delicate, and multitudes of small simple glands open upon its surface. Among these are others (Fig. 37) which possess a somewhat more complicated structure, their blind ends being subdivided. It is these *peptic glands* which, when food passes into the stomach, throw out a thin acid fluid, the *gastric juice.* The acidity arises from the presence of *hydrochloric* or *lactic* acids, but in addition to these constituents the gastric juice possesses another called *pepsin*, which appears to be a substance not altogether dissimilar to *ptyalin* (§ 14).

Thus, when the food passes into the stomach, the contractions of that organ roll it about and mix it thoroughly with the gastric juice.

19. It is easy to ascertain the properties of gastric juice experimentally, by putting a small portion of that part of the mucous membrane which contains the peptic glands into acidulated water containing small pieces of meat, hard boiled egg, or other proteids, and keeping the mixture at a temperature of about 100°. After a few hours it will be found that the white of egg has become dissolved, if not in too great quantity; while all that remains of the meat is a pulp, consisting chiefly of

the connective tissue and fatty matters which it contained. This is *artificial digestion*, and it has been proved by experiment that precisely the same operation takes place when food undergoes natural digestion within the stomach of a living animal.

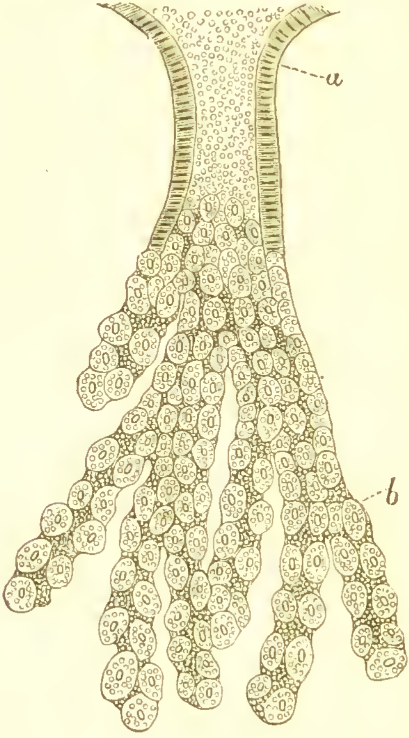

Fig. 37.

One of the glands which secrete the gastric guice, magnified about 350 diameters.

The proteid solution thus effected is called a *peptone*, and has pretty much the same characters, whatever the nature of the proteid which has been digested.

It takes a very long time (some days) for the dilute acid alone to dissolve the protein, and hence the solvent power of gastric juice must be chiefly attributed to the pepsin.

20. By continual rolling about, with constant additions of gastric juice, the food becomes reduced to the consistence of pea-soup, and is called *chyme*. In this state it is, in part, allowed to escape through the pylorus and to enter the duodenum; but a great deal of the fluid (consisting of peptone mixed with saliva, and any saccharine fluids resulting from the partial conversion of starch, or otherwise) is at once absorbed, making its way, by imbibition, through the walls of the delicate and numerous vessels of the stomach into the current of the blood, which is rushing though the gastric veins to the *vena portæ*.

21. The *intestines* form one long tube, with mucous and muscular coats, like the stomach; and like it they are enveloped in peritoneum. They are divided into two portions—the *small intestines* and the *large intestines*, the latter having a much greater diameter than the former. The small intestines again are subdivided into the *duodenum*, the *jejunum*, and the *ileum*, but there is no natural line of demarcation between these. The *duodenum*, however, is distinguishable as that part of the small intestine which immediately succeeds the stomach, and is bent upon itself and fastened by the peritoneum against the back wall of the abdomen in the loop shown in Fig. 36. It is in this loop that the head of the pancreas lies (Fig. 32).

The ileum (*a*, Fig. 38) is no wider than the jejunum or duodenum, so that the transition from the small intestine to the large (*e*) is quite sudden.

The opening of the small intestine into the large is provided with prominent lips which project into the cavity of the latter, and oppose the passage of matters from it into the small intestine, while they readily allow of a passage the other way. This is the *ileo-cæcal* valve (Fig. 38, *d*).

The large intestine forms a blind dilatation beyond the ileo-cæcal valve, which is called the *cæcum;* and from this an elongated blind process is given off, which, from its shape, is called the *vermiform appendix* of the cæcum (Fig. 38, *b*).

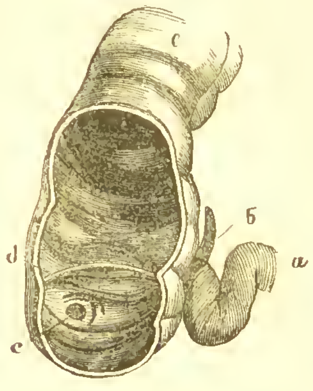

FIG. 38.

The termination of the ileum, *a*, in the cæcum, and the continuation of the latter into the colon, *c*; *d*, the ileo-cæcal valve; *e*, the aperture of the *appendix vermiformis* (*b*) into the cæcum.

The cæcum lies in the lower part of the right side of the abdominal cavity. The *colon*, or first part of the large intestine, passes upwards from it as the *ascending colon;* then making a sudden turn at a right angle, it passes across to the left side of the body, being called the *transverse colon* in this part of its course; and next, suddenly bending backwards along the left side of the abdomen, it becomes the *descending colon.* This reaches the middle line and becomes the *rectum,* which is that part of the large intestine which opens externally.

22. The mucous membrane of the whole intestine is provided with numerous, small, and for the most part simple, glands (named after Lieberkühn and Brunner), which pour into it a secretion, the *intestinal juice,* the precise functions of which are unknown.

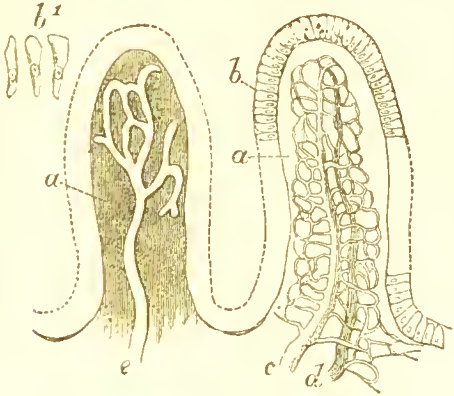

Fig. 39.

Two villi of the small intestines, magnified about 50 diameters.—*a*, substance of the villus; *b*, its epithelium, of which some cells are seen detached at *b′*; *c d*, the artery and vein, with their connecting capillary network, which envelopes and hides *e*, the lacteal radicle which occupies the centre of the villus and opens into a network of lacteal vessels at its base.

Structures peculiar to the small intestine are the *valvulæ conniventes,* transverse folds of the mucous membrane, which increase the surface; and the *villi,* which are minute thread-like processes of the mucous membrane on the *valvulæ conniventes* and elsewhere, set side by side, like the pile of velvet.

Each villus is coated by epithelium, and contains in its interior the radicle, or commencement, of a lacteal vessel (Lesson II. § 6), between which and the surface of the villus lies a capillary network with its afferent artery and efferent vein.

The large intestine presents noteworthy peculiarities in the arrangement of the longitudinal muscular fibres of the colon into three bands, which are shorter than the walls of the intestine itself, so that the latter is thrown into puckers and pouches; and in the disposition of muscular fibres around the termination of the rectum into a ring-like sphincter muscle, which keeps the aperture firmly closed, except when defæcation takes place.

The intestines receive their blood almost directly from the aorta. Their veins carry the blood which has traversed the intestinal capillaries to the *vena portæ.*

The fibres of the muscular coat of the intestines (which lies between its mucous membrane and its serous, or peritoneal, investment) are disposed longitudinally and circularly, and the circular fibres of any part contract, successively, in such a manner that the lower fibres, or those on the side of the anus, contract after the upper ones, or those on the side of the pylorus. It follows from this so-called *peristaltic contraction*, that the contents of the intestines are constantly being propelled, by successive and progressive narrowing of their calibre, from their upper towards their lower parts.

23. The only secretions, besides those of the proper intestinal glands, which enter the intestine, are those of the liver and the pancreas—the *bile* and the *pancreatic juice.* The ducts of these organs have a common opening in the middle of the bend of the

duodenum: and, since the common duct passes obliquely through the coats of the intestine, its walls serve as a kind of valve, obstructing the flow of the contents of the duodenum into the duct, but readily permitting the passage of bile and pancreatic juice into the duodenum (Figs. 32, 36).

As the chyme fills the duodenum, the pancreas comes into activity, and its secretion, with the bile from the gall-bladder, flows through the common aperture, and, mixing with the chyme, converts it into what is called *chyle.*

24. Chyle differs from chyme in two respects. In the first place, the alkali of the bile neutralizes the acid of the chyme; in the second place. both the bile and the pancreatic juice appear to exercise an influence over the fatty matters contained in the chyme, which facilitates the subdivision of these fats into very minute separate particles. The chyme, in fact, which results from the digestion of fatty food, is a mere mixture of watery fluid with oily matters, which are ready to separate from it and unite with one another. In the chyle, on the other hand, the fatty matters are suspended in the fluid, just as oil may be evenly diffused through water by gradually rubbing it up with white of egg into what is termed an *emulsion;* or as the fat (that is, the butter) of milk is naturally held suspended in the watery basis of milk.

The chyle, with these suspended particles, looks white and milky, for the same reason that milk has the same aspect—the multitude of minute suspended fatty particles reflecting a great amount of light.

The conversion of starch into sugar, which seems to be suspended wholly, or partially, so long as the food remains in the stomach, on account of the acidity of the chyme, is resumed as soon as the latter is neutralized, the pancreatic and intestinal juices operating powerfully in this direction.

As the chyle is thrust along the small intestines by the grasping action of the peristaltic contractions, the dissolved matter which it contains is absorbed, in the ordinary way, by the vessels of the villi. The minute particles of fatty matter, on the other hand, are squeezed through the soft substance of the epithelium into that of the villi; and so, in the long run, into the vessels; just as mercury may be squeezed by pressure through the pores of a wash-leather bag.

As the network of capillaries lies outside the lacteal radicle in each villus, it would appear that the blood-vessels must carry off the greater part of the chyle; but much of it enters the lacteals, fills them, and only enters the blood after a roundabout passage through the mesenteric lymphatics and the thoracic duct. (Lesson II. §§ 5, 6.)

25. The digested matters, as they are driven along the small intestines, gradually become deprived of their peptones, fats, and soluble amyloids, and are forced through the ileo-cæcal valve into the cæcum and large intestine. Here they acquire an acid reaction and the characteristic fæcal odour and colour, which become more and more marked as they approach the rectum. It has been supposed that a sort of second digestion occurs in the upper part of the large intestine.

LESSON VII.

MOTION AND LOCOMOTION.

1. In the preceding Lessons the manner in which the incomings of the human body are converted into its outgoings has been explained. It has been seen that new matter, in the form of vital and mineral foods, is constantly appropriated by the body, to make up for the loss of old matter, in the shape, chiefly, of carbonic acid, urea, and water, which is as constantly going on.

The vital foods are derived directly, or indirectly, from the vegetable world; and the products of waste either are such compounds as abound in the mineral world, or immediately decompose into them. Consequently, the human body is the centre of a stream of matter which sets incessantly from the vegetable and mineral worlds into the mineral world again. It may be compared to an eddy in a river, which may retain its shape for an indefinite length of time, though no one particle of the water of the stream remains in it for more than a brief period.

But there is this peculiarity about the human eddy, that a large portion of the particles of matter which flow into it have a much more complex composition than the particles which flow out of it. To speak in what is not altogether a metaphor, the atoms which enter the body are, for the most part, piled up in large heaps, and tumble down into small heaps before they leave it. The force which they set free in thus tumbling down, is the source of the active powers of the organism.

2. These active powers are chiefly manifested in the form of motion—movement, that is, either of part of the body, or of the body as a whole, which last is termed *locomotion*.

The organs which produce total or partial movements of the human body, or of the fluids which it contains, are of two kinds: *Cilia* and *Muscles*.

3. *Cilia* are filaments of extremely small size, attached by their bases to, and indeed growing out from, the free surfaces of epithelial cells (see Lesson XII.). They are in incessant waving motion, so long as life persists in them; and the motion of a cilium continues even for some time after the epithelial cell, with which it is connected, is detached from the body. Not only does the movement of the cilia thus go on independently of the rest of the body, but it cannot be controlled by the action of the nervous system. The cause of the movement of each cilium would appear to be the alternate contraction and relaxation of opposite sides of its base; but why these alternations take place is unknown.

Although no other part of the body has any control over the cilia, and though, so far as we know, they have no direct communication with one another, yet their action is directed towards a common end—the cilia, which cover extensive surfaces, all working in such a manner as to sweep whatever lies upon that surface in one and the same direction. Thus, the cilia which are developed upon the epithelial cells, which line the greater part of the nasal cavities and the trachea, with its ramifications, tend to drive the mucus in which they work, outwards.

In addition to the air-passages, cilia are found, in the human body, in the ventricles of the brain, and in one or two other localities; but the part which they play in man is insignificant in comparison with their function in the lower animals, among many of which they become the chief organs of locomotion.

4. *Muscles* (Lesson I. § 13) are accumulations of fibres, each of which has the power, under certain conditions, of shortening in length, while it increases its other dimensions, so that the absolute volume of the fibre remains unchanged. This power is called *muscular contractility;* and whenever, in virtue of this power, a muscular fibre *contracts,* it tends to bring its two ends, with whatever may be fastened to them, together.

The condition which ordinarily determines the contraction of a muscular fibre is a change of state in a nerve fibre, which is in close anatomical connexion with the muscular fibre. The nerve fibre is thence called a *motor* fibre, because, by its influence on a muscle, it becomes the indirect means of producing motion. (Lesson XI. § 6.)

Muscle is a highly elastic substance. It contains a large amount of water (about as much as the blood), and during life has a clear and semi-transparent aspect.

When subjected to pressure in the perfectly fresh state, and after due precautions have been taken to remove all the contained blood, *striated* muscle (Lesson XII. § 15) yields a fluid which undergoes spontaneous coagulation at ordinary temperatures. At a longer or shorter time after death this coagulation takes place within the muscles themselves.

They become more or less opaque, and, losing their previous elasticity, set into hard rigid masses, which retain the form which they possess when the coagulation commences. Hence the limbs become fixed in the position in which death found them, and the body passes into the condition of what is termed the "death-stiffening," or *rigor mortis.*

After the lapse of a certain time the coagulated matter liquefies, and the muscles pass into a loose and flaccid condition, which marks the commencement of putrefaction.

It has been observed that the sooner *rigor mortis* sets in, the sooner it is over; and the later it commences, the longer it lasts. The greater the amount of muscular exertion and consequent exhaustion before death, the sooner *rigor mortis* sets in.

Muscles may be conveniently divided into two groups, according to the manner in which the ends of their fibres are fastened; into muscles not attached to solid levers, and muscles attached to solid levers.

5. *Muscles not attached to solid levers.*—Under this head come the muscles which are appropriately called *hollow* muscles, inasmuch as they enclose a cavity or surround a space; and their contraction lessens the capacity of that cavity, or the extent of that space.

The muscular fibres of the heart, of the blood-vessels, of the lympathic vessels, of the alimentary canal, of the ducts of the glands, of the iris of the eye, are so arranged as to form hollow muscles.

In the heart the muscular fibres are of the striated kind, and their disposition is exceedingly complex. The cavities which they enclose are those of the auricles and ventricles; and, as we have seen, the fibres, when they contract, do so suddenly and together.

The iris of the eye is like a curtain, in the middle of which is a circular hole. The muscular fibres are of the smooth or not-striated kind (see Lesson XII.), and they are disposed in two ways: some radiating from the edges of the hole to the circumference of the curtain; some arranged in circles, concentrically with the aperture. The muscular fibres contract suddenly and together, the radiating fibres necessarily enlarging the hole, the circular fibres diminishing it.

In the alimentary canal the muscular fibres are also of the unstriated kind, and they are disposed in two layers; one set of fibres being arranged parallel with the length of the intestines, while the others are disposed circularly, or at right angles to the former.

As has been stated above (Lesson VI. § 22), the contraction of these muscular fibres is successive; that is to say, all the muscular fibres, in a given length of the intestines, do not contract at once, but those at one end contract first, and the others follow them until the whole series have contracted. As the order of contraction is, naturally, always the same, from the upper towards the lower end, the effect of this peristaltic contraction is, as we have seen, to force any matter contained in the alimentary canal, from its upper towards its lower extremity. The muscles of the walls of the ducts of the glands have a substantially similar arrangement.

6. *Muscles attached to definite levers.*—The great majority of the muscles in the body are attached to distinct levers, formed by the bones, the minute

structure of which is explained in Lesson XII.

§ 11. In such bones as are ordinarily employed as levers, the osseous tissue is arranged in the form of a *shaft* (Fig. 40, *b*), formed of a very dense and compact osseous matter, but often containing a great central cavity (*b*) which is filled with a very delicate vascular and fibrous tissue loaded with fat called *marrow.* Towards the two ends of the bone, the compact matter of the shaft thins out, and is replaced by a much thicker but looser sponge-work of bony plates and fibres, which is termed the *cancellous* tissue of the bone. The surface even of this part, however, is still formed by a thin sheet of denser bone.

At least one end of each of these bony levers is fashioned into a smooth articular surface, covered with cartilage, which enables the relatively fixed end of the bone to play upon the corresponding surface of some other bone with which it is articulated, or, contrariwise, allows that other bone to move upon it.

It is one or other of these extremities which plays the part of fulcrum when the bone is in use as a lever.

Thus, in the accompanying figure (Fig. 41) of the bones of the upper extremity, with the attachments of the *biceps* muscle to the shoulder-blade and to one of the two bones of the fore-arm called the radius, P indicates the point of action of the power (the contracting muscle) upon the radius.

But to understand the action of the bones, as levers, properly, it is necessary to possess a knowledge of the different kinds of levers, and be able to refer the various combinations of the bones to their appropriate lever-classes.

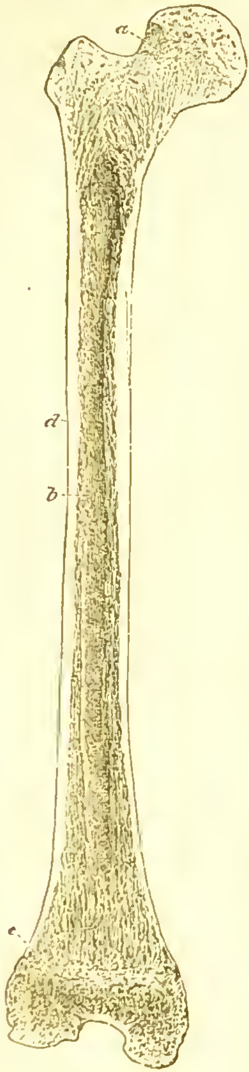

FIG. 40.

Longitudinal section of the shaft of a human femur or thigh-bone: *a*, the head, which articulates with the haunch-bone; *b*, the medullary cavity, and *d*, the dense bony substance, of the shaft; *c*, the part which enters into the knee-joint, articulating with the shin-bone or tibia.

A lever is a rigid bar, one part of which is absolutely or relatively fixed, while the rest is free to move. Some one point of the moveable part of the lever is set in motion by a force, in order to communicate more or less of that motion to another point of the moveable part, which presents a resistance to motion in the shape of a weight or other obstacle.

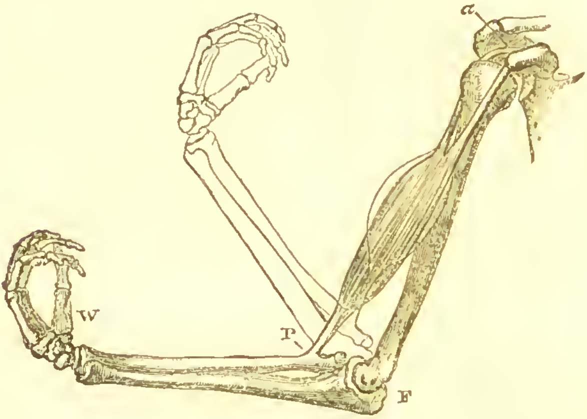

Fig. 41.

The bones of the upper extremity with the biceps muscle. The two tendons by which this muscle is attached to the scapula are seen at *a*. P indicates the attachment of the muscle to the radius, and thence the point of action of the power; F, the fulcrum; W, the weight (of the hand).

Three kinds of levers are enumerated by mechanicians, the definition of each kind depending upon the relative positions of the point of support, or *fulcrum;* of the point which bears the *resistance, weight,* or other obstacle to be overcome by the force; and of the point to which the force, or *power* employed to overcome the obstacle is applied.

If the fulcrum be placed between the power and the weight, so that, when the power sets the lever in motion, the weight and the power describe arcs, the concavities of which are turned towards one another, the lever is said to be of the *first order*. (Fig. 42, I.)

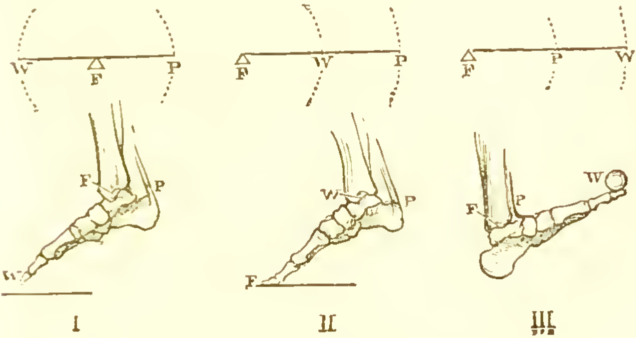

FIG. 42.

The upper three figures represent the three kinds of levers; the lower, the foot, when it takes the character of each kind.—W, weight or resistance; F, fulcrum; P, power.

If the fulcrum be at one end, and the weight be between it and the power, so that weight and power describe concentric arcs, the weight moving through the less space when the lever moves, the lever is said to be of the *second order*. (Fig. 42, II.)

And if, the fulcrum being still at one end, the power be between the weight and it, so that, as in the former case, the power and weight describe concentric arcs, but the power moves through the less space, the lever is of the *third order*. (Fig. 42, III.)

7. In the human body, the following parts present examples of levers of the first order.

(*a*) The skull in its movements upon the atlas, as *fulcrum.*

(*b*) The pelvis in its movements upon the heads of the thigh-bones, as *fulcrum.*

(*c*) The foot, when it is raised, and the toe tapped on the ground, the ankle-joint being *fulcrum.* (Fig. 42, I.)

The positions of the weight and of power are not given in either of these eases, because they are reversed according to circumstances. Thus, when the face is being depressed, the power is applied in front, and the weight to the back part, of the skull; but when the face is being raised, the power is behind and the weight in front. The like is true of the pelvis, according as the body is bent forward, or backward, upon the legs. Finally, when the toes, in the action of tapping, strike the ground, the power is at the heel, and the resistance in the front of the foot. But, when the toes are raised to repeat the act, the power is in front, and the weight, or resistance, is at the heel, being, in fact, the inertia and elasticity of the muscles and other parts of the back of the leg.

But, in all these cases, the lever remains one of the first class, because the fulcrum, or fixed point on which the lever turns, remains between the power and the weight, or resistanee.

8. The following are three examples of levers of the second order:—

(*a*) The thigh-bone of the leg which is bent up towards the body and not used, in the action of hopping.

For, in this case, the fulcrum is at the hip-joint. The power (which may be assumed to be furnished by the *rectus* muscle* of the front of the thigh) acts upon the knee-cap; and the position of the weight is represented by that of the centre of gravity of the thigh and leg, which will lie somewhere between the end of the knee and the hip.

(*b*) A rib when depressed by the *rectus* muscle of the abdomen, in expiration.

Here the fulcrum lies where the rib is articulated with the spine; the power is at the sternum—virtually the opposite end of the rib; and the resistance to be overcome lies between the two.

(*c*) The raising of the body upon the toes, in standing on tiptoe, and in the first stage of making a step forwards. (Fig. 42, II.)

Here the fulcrum is the ground on which the toes rest; the power is applied by the muscles of the calf to the heel; the resistance is so much of the weight of the body as is borne by the ankle-joint of the foot, which of course lies between the heel and the toes.

9. Three examples of levers of the third order are—

(*a*) The spine, head, and pelvis, considered as a rigid bar, which has to be kept erect upon the hip-joints. (Fig. 2.)

Here the fulcrum lies in the hip-joints; the weight is at the centre of gravity of the head and trunk, high above the fulcrum; the power is supplied by the extensor, or flexor, muscles of the thigh, and acts upon points comparatively close to the fulcrum.

* This muscle is attached above to the haunch-bone or *ileum*, and below to the knee-cap. The latter bone is connected by a strong ligament with the *tibia*.

(*b*) Flexion of the forearm upon the arm by the *biceps* muscle, when a weight is held in the hand.

In this case, the weight being in the hand and the fulcrum at the elbow-joint, the power is applied at the point of attachment of the tendon of the biceps, close to the latter. (Fig. 40.)

(*c*) Extension of the leg on the thigh at the knee-joint.

Here the fulcrum is the knee-joint; the weight is at the centre of gravity of the leg and foot; the power is applied through the ligament of the knee-cap, or *patella*, to the tibia, close to the knee-joint.

10. In studying the mechanism of the body, it is very important to recollect that one and the same part of the body may represent each of the three kinds of levers, according to circumstances. Thus it has been seen that the foot may, under some circumstances, represent a lever of the first, in others of the second, order. But it may become a lever of the third order, as when one dances a weight resting upon the toes, up and down, by moving only the foot. In this case, the fulcrum is at the ankle-joint, the weight is at the toes, and the power is furnished by the extensor muscles at the front of the leg, which are inserted between the fulcrum and the weight. (Fig. 42, III.)

11. It is very important that the levers of the body should not slip, or work unevenly, when their movements are extensive, and to this end they are connected together in such a manner as to form strong and definitely arranged *joints* or *articulations.*

Joints may be classified into imperfect and perfect.

(*a*) *Imperfect joints* are those in which the conjoined levers (bones or cartilages) present no smooth surfaces, capable of rotatory motion, to one another, but are connected by continuous cartilages, or ligaments, and have only so much mobility as is permitted by the flexibility of the joining substance.

Examples of such joints as these are to be met with in the vertebral column—the flat surfaces of several joints, or vertebræ, being connected together by thick plates of very elastic fibro-cartilage, which confer upon the whole column considerable play and springiness, and yet prevent any great amount of

FIG. 43.

A section of the hip-joint taken through the acetabulum and the middle of the head and neck of the thigh-bone.—*L.T.* Ligamentum teres, or round ligament.

motion between the several vertebræ. The pubic-bones are united together, and the haunch-bones with the sacrum, by fibrous or cartilaginous tissue, which allows of only a slight play, or may merely confer a little more elasticity than if the union were effected by the direct apposition of the bones.

(*b*) In all perfect joints, the opposed surfaces of the bones which move upon one another are covered with cartilage, and are contained in a sort of sac, which lines these cartilages and the side walls of the joint; and which, secreting a viscid lubricating fluid—the *synovia*—is called a *synovial membrane.*

12. The opposed surfaces of the *articular* cartilages are spheroidal, cylindrical, or pulley-shaped; and the convexities of the one answer, more or less completely, to the concavities of the other.

Sometimes, the two articular cartilages do not come directly into contact, but are separated by independent plates of cartilage, which are termed *inter-articular.* The opposite faces of these inter-articular cartilages are fitted to receive the faces of the proper articular cartilages.

While these co-adapted surfaces and synovial membranes provide for the free mobility of the bones entering into a joint, the nature and extent of their motion is defined, partly by the forms of the articular surfaces, and partly by the disposition of the *ligaments*, or firm fibrous cords which pass from one bone to the other.

13. As respects the nature of the articular surfaces, joints may be what are called *ball and socket joints*, when the spheroidal surface furnished by one bone plays in a cup furnished by another. In this case the motion of the former bone may take place in any direction, but the extent of the motion

depends upon the shape of the cup—being very great when the cup is shallow, and small in proportion as it is deep. The shoulder is an example of a ball and socket joint with a shallow cup; the hip of such a joint with a deep cup (Fig. 43).

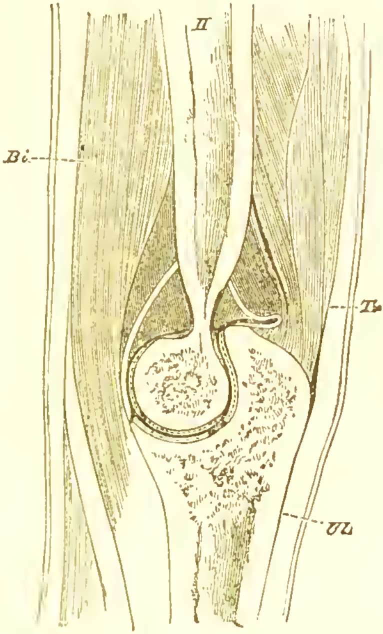

FIG. 44.

Longitudinal and vertical section through the elbow-joint.—*H.* Humerus; *Ul.* ulna; *Tr.* the *triceps* muscle which extends the arm; *Bi.* the *biceps* muscle which flexes it.

14. *Hinge-joints* are single or double. In the former case, the nearly cylindrical head of one bone fits into a corresponding socket of the other. In this form of hinge-joint the only motion possible is

in the direction of a plane perpendicular to the axis of the cylinder, just as a door can only be made to move round an axis passing through its hinges. The elbow is the best example of this joint in the human body (Fig. 44). The knee and ankle present less perfect specimens of it.

A double hinge-joint is one in which the articular surface of each bone is concave in one direction, and convex in another, at right angles to the former. A man seated in a saddle is "articulated" with the saddle by such a joint. For the saddle is concave from before backwards and convex from side to side, while the man presents to it the concavity of his legs astride, from side to side, and the convexity of his seat, from before backwards.

The metacarpal bone of the thumb is articulated with the bone of the wrist, called *trapezium*, by a double hinge-joint.

15. A *pivot-joint* is one in which a given bone furnishes a pivot, on which another turns; or itself turns on its own axis, resting on another bone. A remarkable example of the former arrangement is afforded by the *atlas* and *axis*, or two uppermost vertebræ of the neck (Fig. 45). The axis possesses a vertical peg, the so-called *odontoid* process (*b*), and at the base of the peg are two, obliquely-placed, articular surfaces (*a*). The atlas is a ring-like bone, with a massive thickening on each side. The inner side of the front of the ring plays round the neck of the odontoid peg, and the under surfaces of the lateral masses glide over the articular faces on each side of the base of the peg. A strong ligament passes between the inner sides of the two lateral masses of the atlas, and keeps the hinder side of the neck of the odontoid peg in its place

(Fig. 45, A). By this arrangement, the atlas is enabled to rotate through a considerable angle either way upon the axis, without any danger of falling forwards or backwards—accidents which would immediately destroy life by crushing the spinal marrow.

The lateral masses of the atlas have, on their upper faces, concavities (Fig. 45, A, *a*) into which

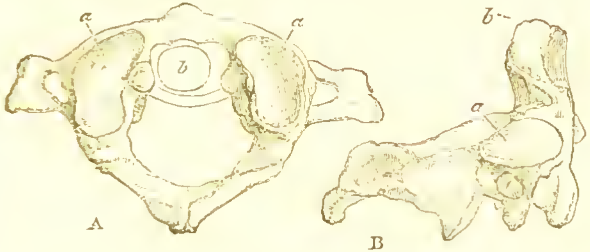

Fig. 45.

A. The Atlas viewed from above: *a a*, upper articular surfaces of its lateral masses for the condyles of the skull; *b*, the peg of the axis vertebra. B. Side view of the axis vertebra: *a*, articular surface for the lateral mass of the atlas; *b*, peg or odontoid process.

the two convex, occipital condyles of the skull fit, and in which they play upward and downward. Thus the nodding of the head is effected by the movement of the skull upon the atlas; while, in turning the head from side to side, the skull does not move upon the atlas, but the atlas slides round the odontoid peg of the axis vertebra.

The second kind of pivot-joint is seen in the forearm. If the elbow and forearm, as far as the wrist, are made to rest upon a table, and the elbow is kept firmly fixed, the hand can nevertheless be freely rotated so that either the palm, or the back, is turned directly upwards. When the palm is turned upwards, the attitude is called *supination*

(Fig. 46, A); when the back, *pronation* (Fig. 46, B).

The forearm is composed of two bones; one, the *ulna,* which articulates with the *humerus* at the elbow by the hinge-joint already described, in such a manner that it can move only in flexion and extension, and has no power of rotation. Hence, when the elbow and wrist are rested on a table, this bone remains unmoved.

But the other bone of the forearm, the *radius,* has its small upper end shaped like a very shallow cup with thick edges. The hollow of the cup articulates with a spheroidal surface furnished by the humerus; the lip of the cup, with a concave depression on the side of the ulna.

The large lower end of the radius bears the hand, and has, towards the ulna, a concave surface, which articulates with the convex side of the small lower end of that bone.

Thus the upper end of the radius turns on the double surface, furnished to it by the pivot-like ball of the humerus, and the partial cup of the ulna; while the lower end of the radius can rotate round the surface furnished to it by the lower end of the ulna.

In *supination,* the radius lies parallel with the ulna, with its lower end to the outer side of the ulna (Fig. 46, A). In *pronation,* it is made to turn on its own axis above, and round the ulna below, until its lower moiety crosses the ulna, and its lower end lies on the inner side of the ulna (Fig. 46, B).

16. The ligaments which keep the mobile surfaces of bones together are, in the case of ball and socket joints, strong fibrous *capsules* which surround the joint on all sides. In hinge-joints, on the other

hand, the ligamentous tissue is chiefly accumulated, in the form of *lateral ligaments*, at the sides of the

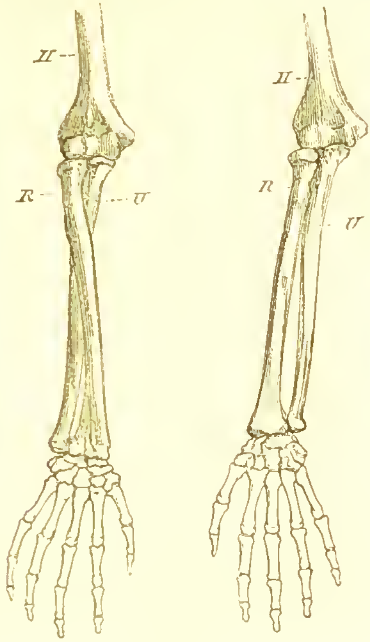

FIG. 46.

The bones of the right forearm in supination (A) and pronation (B): *H*, humerus; *R*, radius; *U*, ulna.

joints. In some cases ligaments are placed within the joints, as in the knee, where the bundles of fibres which cross obliquely between the femur and the tibia are called *crucial* ligaments; or, as in the hip, where the *round ligament* passes from the bottom of the acetabulum to the ball furnished by the head of the femur (Fig. 43).

Again, two ligaments pass from the apex of the odontoid peg to either side of the margins of the occipital foramen; these, from their function in helping to stop excessive rotation of the skull, are called *check ligaments* (Fig. 47, *a*).

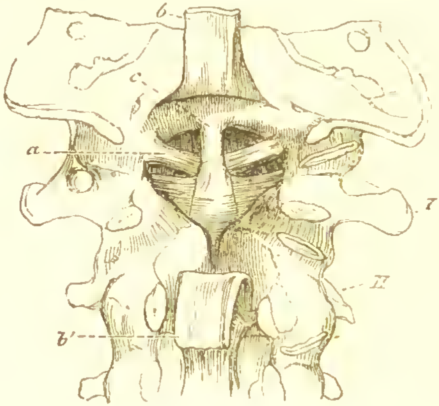

Fig. 47.

The vertebral column in the upper part of the neck laid open, to show—*a*, the check ligaments of the axis; *b*, the broad ligament which extends from the front margin of the occipital foramen along the hinder faces of the bodies of the vertebræ; it is cut through, and the cut ends turned back to show, *c*, the special ligament which connects the point of the "odontoid" peg with the front margin of the occipital foramen; *I.* the atlas; *II.* the axis.

In one joint of the body, the hip, the socket or *acetabulum* (Fig. 43) fits so closely to the head of the femur, and the capsular ligament so completely closes its cavity on all sides, that the pressure of the air must be reckoned among the causes which prevent dislocation. This has been proved experimentally by boring a hole through the floor of the acetabulum, so as to admit air into its cavity, when the thigh-bone at once falls as far as the round and capsular ligaments will permit it to do, showing that it was previously pushed close up by the pressure of the external air.

17. The different kinds of movement which the levers thus connected are capable of performing, are called *flexion* and *extension; abduction* and *adduction; rotation* and *circumduction.*

A limb is *flexed,* when it is bent; *extended,* when it is straightened out. It is *abducted,* when it is drawn away from the middle line; *adducted,* when it is brought to it. It is *rotated,* when it is made to turn on its own axis; *circumducted,* when it is made to describe a conical surface by rotation round an imaginary axis.

No part of the body is capable of perfect rotation like a wheel, for the simple reason that such motion would necessarily tear all the vessels, nerves, muscles, &c. which unite it with other parts.

18. Given two bones united by a joint, and they may be moved one upon another in, at fewest, two different directions. In the case of a pure hinge-joint, their directions must be opposite and in the same plane; but, in all other joints, they may be in several directions and in various planes.

In the case of a pure hinge-joint, the two practicable movements will be effected by attaching muscles to the respective bones on opposite sides of the joint; *i.e.* one on the side *towards* which one of the bones moves, and one on the side *from* which it moves, when the joint is bent. When either of these muscles contracts, it will pull its attached ends together, and bend or straighten, as the case may be, the joint towards the side on which it is placed.

Thus the *biceps* muscle (*Bi.,* Fig. 44) flexes, and the *triceps* (*Tr.*, Fig. 44) extends, the forearm upon the arm.

In the other extreme form of articulation—the ball and socket joint—movement in any number of planes may be effected, by attaching muscles in corresponding number and direction, on the one hand, to the bone which affords the socket, and on the other to that which furnishes the head. Circumduction will be effected by the combined and successive contraction of these muscles.

19. It usually happens that the bone to which one end of a muscle is attached is absolutely or relatively stationary, while that to which the other is fixed is moveable. In this case, the attachment to the stationary bone is termed the *origin*, that to the moveable bone the *insertion*, of the muscle.

The fibres of muscles are sometimes fixed directly into the parts which serve as their origins and insertions: but, more commonly, strong cords or bands of fibrous tissue, called *tendons*, are interposed between the muscle proper and its place of origin or insertion. When the tendons play over hard surfaces, it is usual for them to be separated from these surfaces by sacs containing fluid, which are called *bursæ;* or even to be invested by synovial sheaths.

Usually, the direction of the axis of a muscle is that of a straight line joining its origin and its insertion. But in some muscles, as the *superior oblique muscle* of the eye, the tendon passes over a pulley formed by ligament, and completely changes its direction before reaching its insertion. (See Lesson IX.)

Again, there are muscles which are fleshy at each end, and have a tendon in the middle. Such muscles are called *digastric*, or two-bellied. In the curious muscle which depresses the lower jaw, and specially receives this name of *digastric*, the middle tendon runs through a pulley connected with the hyoid bone; and the muscle, which passes downwards and forwards from the skull to this pulley, after traversing it, runs upwards and forwards, to the lower jaw (Fig. 48).

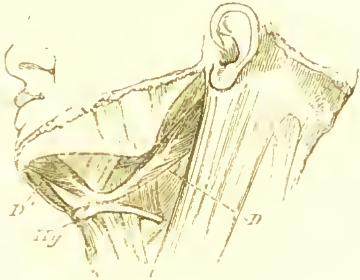

FIG. 48.

The course of the digastric muscle.—*D*, its posterior belly; *D'*, its anterior belly; between the two is the tendon passing through its pulley connected with *Hy*. the hyoid bone.

20. We may now pass from the consideration of the mechanism of mere motion to that of locomotion.

When a man who is standing erect on both feet proceeds to *walk*, beginning with the right leg, the body is inclined so as to throw the centre of gravity forward; and, the right foot being raised, the right leg is advanced for the length of a step, and the foot is put down again. In the meanwhile, the left heel is raised, but the toes of the left foot have not left the ground when the right foot has reached it, so that there is no moment when both feet are off the ground. For an instant, the legs form two sides of an equilateral triangle, and the centre of the body is consequently lower than it was when the legs were parallel and close together.

The left foot, however, has not been merely dragged away from its first position, but the muscles of the calf, having come into play, act upon the foot as a lever of the second order, and thrust the body, the weight of which rests largely on the left astragalus, upwards, forwards, and to the right side. The momentum thus communicated to the body causes it, with the whole right leg, to describe an arc over the right astragalus, on which that leg rests below. The centre of the body consequently rises to its former height as the right leg becomes vertical, and descends again as the right leg, in its turn, inclines forward.

When the left foot has left the ground, the body is supported on the right leg, and is well in advance of the left foot; so that, without any further muscular exertion, the left foot swings forward like a pendulum, and is carried by its own momentum, beyond the right foot, to the position in which it completes the second step.

When the intervals of the steps are so timed that each swinging leg comes forward into position for a new step without any exertion on the part of the walker, walking is effected with the greatest possible economy of force. And, as the swinging leg is a true pendulum,—the time of vibration of which depends, other things being alike, upon its length (short pendulums vibrating more quickly than long ones),—it follows that, on the average, the natural step of short-legged people is quicker than that of long-legged ones.

In *running* there is a period when both legs are off the ground. The legs are advanced by muscular contraction, and the lever action of each foot is swift and violent. Indeed, the action of each leg resembles, in violent running, that which, when both legs act together, constitutes a *jump*, the sudden extension of the legs adding to the impetus, which, in slow walking, is given only by the feet.

21. Perhaps the most singular motor apparatus in the body is the *larynx*, by the agency of which *voice* is produced.

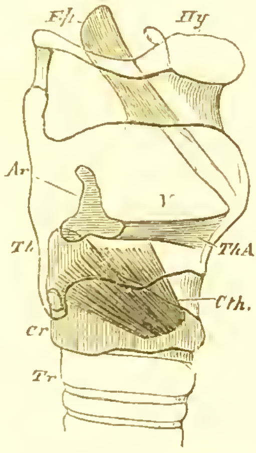

FIG. 49.

Diagram of the larynx, the thyroid cartilage being supposed to be transparent, and allowing the right arytenoid cartilage (*Ar.*), vocal ligament (*V.*), and thyro-arytenoid muscle (*Th. A.*), the upper part of the cricoid cartilage (*Cr.*), and the attachment of the epiglottis (*Ep.*), to be seen. *C.th.* the right crico-thyroid muscle; *Tr.* the trachea; *Hy.* the hyoid bone.

The essential conditions of the production of the human voice are:—

a. The existence of the so-called *vocal chords.*

b. The parallelism of the edges of these chords, without which they will not vibrate in such a manner as to give out sound.

c. A certain degree of tightness of the vocal chords, without which they will not vibrate quickly enough to produce sound.

d. The passage of a current of air between the parallel edges of the vocal chords of sufficient power to set the chords vibrating.

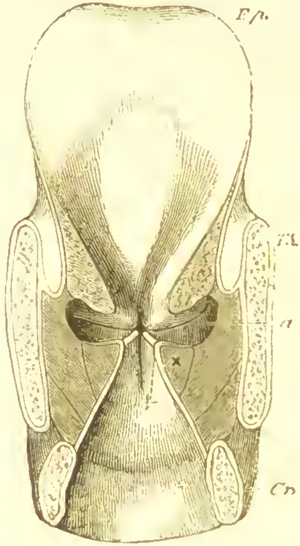

FIG. 50.

A vertical and transverse section through the larynx, the hinder half of which is removed.—*Ep.* Epiglottis; *Th.* thyroid cartilage; *a*, cavities called the *ventricles of the larynx* above the vocal ligaments (*V*); × the right thyro-arytenoid muscle cut across; *Cr.* the cricoid cartilage.

22. The *vocal chords* are, properly speaking, not "chords" at all, but elastic cushions with broad bases, fixed to the larynx, and sharp free edges, which constitute the lateral boundaries of the glottis. In front, the ends of the edges of these vocal cushions are attached, close together, to the re-entering angle of the *thyroid cartilage;* behind, to the *arytenoid cartilages.* These, when left to themselves, diverge, so that, in the quiescent state, the aperture of the glottis is V-shaped, the point of the V being forwards and the base behind (Fig. 51). Under these circumstances a current of air passing through the glottis produces no sound; whence it is that ordinary expiration and inspiration take place quietly.

23. The thyroid cartilage is a broad plate of gristle bent upon itself into a V shape, and so disposed that the point of the V is turned forwards, and constitutes what is commonly called "Adam's apple." Above, the thyroid cartilage is attached to the hyoid bone. Below and behind, its broad sides are produced into little elongations or horns, which are connected by ligaments with the outside of a great ring of cartilage, the *cricoid,* which forms, as it were, the top of the windpipe.

The cricoid ring is much higher behind than in front, and a gap, filled up by membrane only, is left between its upper edge and the lower edge of the front part of the thyroid, when the latter is horizontal. Consequently, the thyroid cartilage, turning upon the articulation of its horns with the hinder part of the cricoid, as upon hinges, can be moved up and down through the space left by this membrane. When it moves downwards, the distance between the front part of the thyroid cartilage and the back of the cricoid is necessarily increased; and when it moves back again to the horizontal position, diminished. There is, on each side, a large muscle, the *crico-thyroid*, which passes from the outer side of the cricoid cartilage obliquely upwards and backwards to the thyroid, and pulls the latter down (Fig. 49, *C.th*).

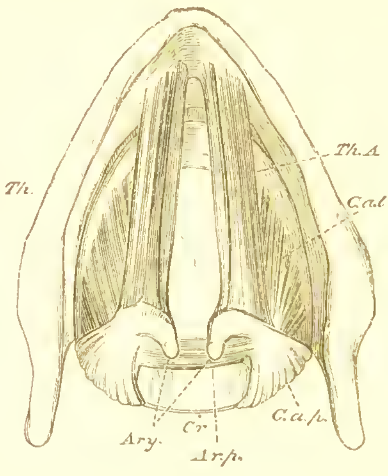

FIG. 51.

The parts surrounding the glottis partially dissected and viewed from above.—*Th.* The thyroid cartilage; *Cr.* the cricoid cartilage; *V.* the edges of the vocal ligaments bounding the glottis; *Ary.* the arytenoid cartilages; *Th.A.* thyro-arytenoid; *C.a.l.* lateral crico-arytenoid; *C.a.p.* posterior crico-arytenoid; *Ar.p.* posterior arytenoid muscles.

24. The two *arytenoid* cartilages are perched side by side upon the upper edge of the back part of the cricoid, and are freely articulated therewith. Muscles are so disposed as to pull them towards, or away from, one another; and a pair of strong muscles which proceed from their bases to the re-entering angle of the thyroid alongside the vocal

chords, and are called *thyro-arytenoid*, tend to pull the thyroid cartilage up when it has been depressed by the crico-thyroid muscles.

When the muscles called *posterior arytenoid*, which, passing between the two arytenoid cartilages, cause them to approach one another, contract, they bring the hinder ends of the vocal chords together, and make their edges parallel. The expiratory muscles now force air from the chest through the larynx, and a musical note, the voice, is produced.

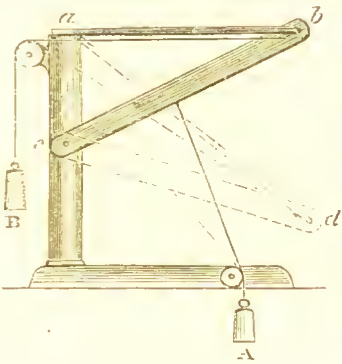

FIG. 52.

Diagram of a model illustrating the action of the levers and muscles of the larynx. The stand and vertical pillar represent the cricoid and arytenoid cartilages, while the rod (*b c*), moving on a pivot at *c*, takes the place of the thyroid cartilage; *a b* is an elastic band representing the vocal ligament. Parallel with this runs a cord fastened at one end to the rod *b c*, and, at the other, passing over a pulley to the weight B. This represents the thyro-arytenoid muscle. A cord attached to the middle of *b c*, and passing over a second pulley to the weight A, represents the crico-thyroid muscle. It is obvious that when the bar (*b c*) is pulled down to the position *c d*, the elastic band (*a b*) is put on the stretch.

25. Other things being alike, the musical note will be low or high, according as the vocal chords

are relaxed or tightened; and this again depends upon the relative predominance of the contraction of the crico-thyroid and thyro-arytenoid muscles. For when the thyro-arytenoid muscles are fully contracted, the thyroid cartilage will be pulled up as far as it can go, and the vocal chords will be rendered relatively lax; while, when the crico-thyroid muscles are fully contracted, the thyroid cartilage will be depressed as much as possible, and the vocal chords will be made more tense.

The *range* of any voice depends upon the difference of tension which can be given to the vocal chords, in these two positions of the thyroid cartilage. *Accuracy* of singing depends upon the precision with which the singer can voluntarily adjust the contractions of the thyro-arytenoid and crico-thyroid muscles—so as to give his vocal chords the exact tension at which their vibration will yield the notes required.

The *quality* of a voice—treble, bass, tenor, &c. —on the other hand, depends upon the make of the particular larynx, the primitive length of its vocal chords, their elasticity, the amount of resonance of the surrounding parts, and so on.

Thus, men have deeper notes than boys and women, because their larynxes are larger and their vocal chords longer—whence, though equally elastic, they vibrate less swiftly.

26. *Speech* is voice modulated by the throat, tongue, and lips. Thus, voice may exist without speech; and it is commonly said that speech may exist without voice, as in whispering. This is only true, however, if the title of voice be restricted to the sound produced by the vibration of the vocal chords;

for, in whispering, there is a sort of voice produced by the vibration of the muscular walls of the lips, which thus replace the vocal chords. A whisper is, in fact, a very low whistle.

The *modulation* of the voice into speech is effected by changing the form of the cavity of the mouth and nose, by the action of the muscles which move the walls of those parts.

Thus, if the pure *vowel* sounds—

E (as in *he*),	*A* (as in *hay*),	*A′* (as in *ah*),
O (as in *or*),	*O′* (as in *oh*),	*OO* (as in *cool*),

are pronounced successively, it will be found that they may be all formed out of the sound produced by a continuous expiration, the mouth being kept open, but the form of its aperture being changed for each vowel. It will be narrowest, with the lips most drawn back, in *E*, widest in *A′*, and roundest, with the lips most protruded, in *OO*.

Certain *consonants* also may be pronounced without interrupting the current of the expired air, by modification of the form of the throat and mouth.

Thus the aspirate, *H*, is the result of a little extra expiratory force—a sort of incipient cough. *S* and *Z*, *Sh* and *J* (as in *jugular*=*G* soft, as in *gentry*), *Th*, *L*, *R*, *F*, *V*, may likewise all be produced by continuous currents of air forced through the mouth, the shape of the cavity of which is peculiarly modified by the tongue and lips.

27. All the vocal sounds hitherto noted so far resemble one another, that their production does not involve the stoppage of the current of air which traverses either of the modulating passages.

But the sounds of *M* and *N* can only be formed by blocking the current of air which passes through the mouth, while free passage is left through the nose. For *M*, the mouth is shut by the lips; for *N*, by the application of the tongue to the palate.

28. The other consonantal sounds of the English language are produced by shutting the passage through both nose and mouth; and, as it were, forcing the expiratory vocal current through the obstacle furnished by the latter, the character of which obstacle gives each consonant its peculiarity. Thus, in producing the consonants *B* and *P*, the mouth is shut by the lips, which are then forced open in this *explosive* manner. In *T* and *D*, the mouth passage is suddenly barred by the application of the point of the tongue to the teeth, or to the front part of the palate; while in *K* and *G* (hard, as in *go*) the middle and back of the tongue are similarly forced against the back part of the palate.

29. An artificial larynx may be constructed by properly adjusting elastic bands, which take the place of the vocal chords; and, when a current of air is forced through these, due regulation of the tension of the bands will give rise to all the notes of the human voice. As each vowel and consonantal sound is produced by the modification of the form of the cavities, which lie over the natural larynx; so, by placing over the artificial larynx chambers to which any requisite shape can be given, the various letters may be sounded. It is by attending to these facts and principles that various speaking machines have been constructed.

30. Although the tongue is credited with the responsibility of speech, as the "unruly member," and undoubtedly takes a very important share in its production, it is not absolutely indispensable. Hence, the apparently fabulous stories of people who have

been enabled to speak, after their tongues had been cut out by the cruelty of a tyrant or persecutor, may be quite true.

Some years ago I had the opportunity of examining a person, whom I will call Mr. R., whose tongue had been removed as completely as a skilful surgeon could perform the operation. When the mouth was widely opened, the truncated face of the stump of the tongue, apparently covered with new mucous membrane, was to be seen, occupying a position as far back as the level of the anterior pillars of the fauces. The dorsum of the tongue was visible with difficulty; but I believe I could discern some of the circumvallate papillæ upon it. None of these were visible upon the amputated part of the tongue, which had been preserved in spirit; and which, so far as I could judge, was about 2½ inches long.

When his mouth was open, Mr. R. could advance his tongue no further than the position in which I saw it; but he informed me that when his mouth was shut, the stump of the tongue could be brought much more forward.

Mr. R.'s conversation was perfectly intelligible; and such words as *think*, *the*, *cow*, *kill*, were well and clearly pronounced. But tin became *fin;* tack, *fack* or *pack;* toll, *pool;* dog, *thog;* dine, *vine;* dew, *thew;* cat, *catf;* mad, *madf;* goose, *gooth;* big, pig, *bich*, *pich*, with a guttural *ch*.

In fact, only the pronunciation of those letters the formation of which requires the use of the tongue was affected; and, of these, only the two which involve the employment of its tip were absolutely beyond Mr. R.'s power. He converted all *t's* and *d's* into *f's*, *p's*, *v's*, or *th's*. *Th* was fairly given in all cases; *s* and *sh*, *l* and *r*, with more or less of a lisp.

Initial *g's* and *k's* were good; but final *g's* were all more or less guttural. In the former case, the imperfect stoppage of the current of air by the root of the tongue was of no moment, as the sound ran on into that of the following vowel; while, when the letter was terminial, the defect at once became apparent.

LESSON VIII.

SENSATIONS AND SENSORY ORGANS.

1. The agent by which all the motor organs (except the cilia) described in the preceding Lesson are set at work, is muscular fibre. But, in the living body, muscular fibre is made to contract only by a change which takes place in the *motor* or *efferent nerve*, which is distributed to it. This change again is effected only by the activity of the *central nervous organ*, with which the motor nerve is connected. The central organ is thrown into activity immediately or ultimately, only by the influence of changes which take place in the molecular condition of nerves, called *sensory* or *afferent*, which are connected, on the one hand, with the central organ, and, on the other hand, with some other part of the body. Finally, the alteration of the afferent nerve is itself produced only by changes in the condition of the part of the body with which it is connected, and which usually result from external impressions.

2. Thus, the great majority (if not the whole) of the movements of the body and of its parts, are the effect of an influence (technically termed a *stimulus* or *irritation*) applied directly, or indirectly, to the ends of *afferent nerves*, and giving rise to a molecular change, which is propagated along their substance to the *central nervous organ* with which they are connected. The molecular activity of the afferent

nerve communicates itself to the central organ, and is then transmitted along the *motor nerves,* which pass from the central organ to the muscles affected. And, when the disturbance in the molecular condition of the efferent nerves reaches their extremities, it is communicated to the muscular fibres, and causes their particles to take up a new position, so that each fibre shortens and becomes thicker.

3. Such a series of molecular changes as that just described is called a *reflex action*—the disturbance caused by the irritation being as it were *reflected* back, along the motor nerves, to the muscles.

A reflex action, strictly so called, takes place without our knowing anything about it, and hundreds of such actions are going on continually in our bodies without our being aware of them. But it very frequently happens that we learn that something is going on, when a stimulus affects our afferent nerves, by having what we call a *feeling* or *sensation.* We class sensations along with *emotions,* and *volitions,* and *thoughts,* under the common head of *states of consciousness.* But what consciousness is, we know not; and how it is that anything so remarkable as a state of consciousness comes about as the result of irritating nervous tissue, is just as unaccountable as the appearance of the Djin when Aladdin rubbed his lamp, or as any other ultimate fact of nature.

4. Sensations are of very various degrees of definiteness. Some arise within ourselves, we know not how or where, and remain vague and undefinable. Such are the sensations of *uncomfortableness,* or *faintness,* of *fatigue,* or of *restlessness.* We cannot assign any particular place to these sensations, which are very probably the result of affections of the

afferent nerves in general, by the state of the blood, or that of the tissues in which they are distributed. And however real these sensations may be, and however largely they enter into the sum of our pleasures and pains, they tell us absolutely nothing of the external world. They are not only *diffuse*, but they are also *subjective* sensations.

5. What is termed the *muscular sense* is less vaguely localized than the preceding, though its place is still incapable of being very accurately defined. This muscular sensation is the feeling of resistance which arises when any kind of obstacle is opposed to the movement of the body, or of any part of it; and it is something quite different from the feeling of contact, or even of pressure.

Lay one hand flat on its back upon a table, and rest a disc of cardboard a couple of inches in diameter upon the ends of the outstretched fingers; the only result will be a sensation of *contact*—the pressure of so light a body being inappreciable. But put a two-pound weight upon the cardboard, and the sensation of *contact* will be accompanied, or even obscured, by the very different feeling of *pressure*. Up to this moment the fingers and arm have rested upon the table; but now let the hand be raised from the table, and another new feeling will make its appearance—that of *resistance to effort*. This feeling comes into existence with the exertion of the muscles which raise the arm, and is the consciousness of that exertion given to us by the muscular sense.

Any one who raises or carries a weight, knows well enough that he has this sensation; but he may be greatly puzzled to say where he has it. Nevertheless, the sense itself is very delicate, and enables us to form tolerably accurate judgments of the relative intensity of resistances. Persons who deal in articles sold by weight, are constantly enabled to form very precise estimates of the weight of such articles by balancing them in their hands; and, in this case, they depend in a great measure upon the muscular sense.

6. In a third group of sensations, each feeling, as it arises, is assigned to a definite part of the body, and is produced by a stimulus applied to that part of the body; but the bodies, or forces, which are competent to act as stimuli, are very various in character. Such are the sensations of *touch, taste,* and *smell,* which are restricted to the membranes covering the surface of the body, and lining the mouth and nasal cavities.

And lastly, in a fourth group of sensations, each feeling requires for its production the application of a single kind of stimulus to a very specially modified part of the integument. The latter serves as an intermediator between the physical agent of the sensation and the sensory nerve, which is to convey to the brain the impulse necessary to awake in it that state of consciousness which we call the sensation. Such are the sensations of *sight* and *hearing.* The physical agents which can alone awaken these sensations (under natural circumstances) are light and sound. The modified parts of the integument, which alone are competent to intermediate between these agents and the nerves of sight and hearing, are the *eye* and the *ear.*

7. In every sensory organ it is necessary to distinguish the terminal expansion of the afferent or sensory nerve, and the structures which intermediate between this expansion and the physical agent which gives rise to the sensation.

And in each group of special sensations there are certain phenomena which arise out of the structure of the organ, and others which result from the operation of the central apparatus of the nervous system upon the materials supplied to it by the sensory organ.

8. The sense of TOUCH (including that of heat and cold) is possessed, more or less acutely, by all parts of the free surface of the body, and by the walls of the mouth and nasal passages.

Whatever part possesses this sense consists of a membrane (integumentary or mucous) composed of a deep layer made up of fibrous tissue, containing a capillary network and the ultimate terminations of the sensory nerves; and of a superficial layer consisting of epithelial or epidermic cells, among which are neither nerves nor vessels.

Wherever the sense of touch is delicate, the deep layer is not a mere flat expansion, but is raised up into multitudes of small, close-set, conical elevations, which are called *papillæ*. In the skin, the coat of epithelial or epidermic cells does not follow the contour of these papillæ, but dips down between them and forms a tolerably even coat over them. Thus, the points of the papillæ are much nearer the surface than the general plane of the deep layer whence these papillæ proceed.

Loops of vessels enter the papillæ, and the fine ultimate terminations of the sensory nerve-fibres distributed to the skin terminate in them, but in what way has not been thoroughly made out.

In certain cases, the delicate fibrous sheath, or *neurilemma*, of the nerve which enters the papilla, enlarges in the papilla into an oval swelling, which is called a *tactile corpuscle* (see Lesson XII.). These corpuscles are only found in the papillæ of those localities which are endowed with a very delicate sense of touch, as in the tips of the fingers, the point of the tongue, &c.

9. It is obvious, from what has been said, that no direct contact takes place between a body which is touched and the sensory nerve, a thicker or thinner layer of epithelium, or epidermis, being situated between the two. In fact, if this layer is removed, as when a surface of the skin has been blistered, contact with the raw surface gives rise to a sense of pain, not to one of touch properly so called. Thus, in touch, it is the epidermis, or epithelium, which is the intermediator between the nerve and the physical agent, the external pressure being transmitted through the horny cells to the subjacent ends of the nerves, and the kind of impulse thus transmitted must be modified by the thickness and character of the cellular layer, no less than by the forms and number of the papillæ.

10. Certain very curious phenomena appertaining to the sense of touch, are probably due to these varying anatomical arrangements. Not only is tactile sensibility to a single impression much duller in some parts than in others—a circumstance which might be readily accounted for by the different thickness of the cellular layer—but the power of distinguishing double simultaneous impressions is very different. Thus, if the ends of a pair of compasses (which should be blunted with pointed pieces of cork) are separated by only one-tenth or one-twelfth of an inch, they will be distinctly felt as two, if applied to the tips of the fingers; whereas, if applied to the back of the hand in the

same way, only one impression will be felt; and, on the arm, they may be separated for a quarter of an inch, and still only one impression will be perceived.

Accurate experiments have been made in different parts of the body, and it has been found that two points can be distinguished by the tongue, if only one-twenty-fourth of an inch apart; by the tips of the fingers if one-twelfth of an inch distant; while they may be one inch distant on the cheek, and even three inches on the back, and still give rise to only one sensation.

11. The feeling of warmth, or cold, is the result of an excitation of sensory nerves distributed to the skin, which are probably distinct from those which give rise to the sense of touch. And it would appear that the heat must be transmitted through the cellular layer, to give rise to this sensation; for just as touching a naked nerve, or the trunk of a nerve, gives rise only to pain, so heating or cooling an exposed nerve, or the trunk of a nerve, gives rise not to a sensation of heat or cold, but simply to pain.

Again, the sensation of heat, or cold, is relative rather than absolute. Suppose three basins be prepared, one filled with ice-cold water, one with water as hot as can be borne, and the third with a mixture of the two. If the hand be put into the hot water basin, and then transferred to the mixture, the latter will feel cold; but if the hand be kept awhile in the ice-cold water, and then transferred to the very same mixture, it will feel warm.

Like the sense of touch, the sense of warmth varies in delicacy in different parts of the body.

The cheeks are very sensitive, more so than the lips; the palms of the hands are more sensitive to heat than their backs. Hence a washerwoman holds her flat-iron to her cheek to test the temperature, and one who is cold spreads the palms of his hands to the fire.

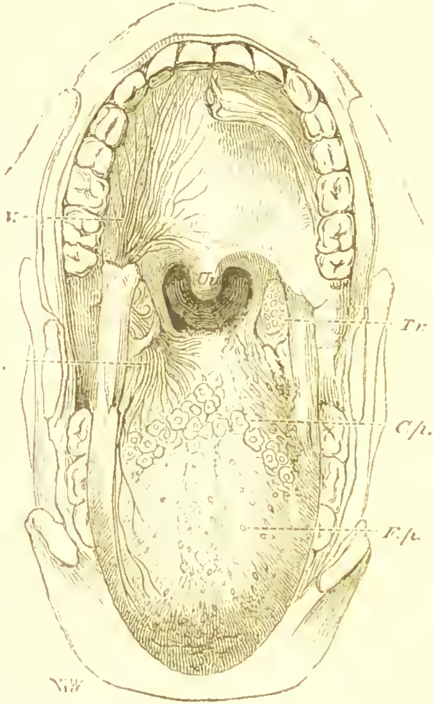

FIG. 53.

The mouth widely opened to show the tongue and palate.—*Uv.* the uvula; *Tr.* the tonsil between the anterior and posterior pillars of the fauces; *C.p.* circumvallate papillæ; *F.p.* fungiform papillæ. The minute filiform papillæ cover the interspaces between these. On the right side the tongue is partially dissected to show the course of the filaments of the glossopharyngeal nerve, *IX.*

12. The organ of the sense of TASTE is the mucous membrane which covers the tongue, especi-

ally its back part, and the hinder part of the palate. Like that of the skin, the deep, or vascular, layer of the mucous membrane of the tongue is raised up into papillæ, but these are large, separate, and have separate coats of epithelium. Towards the tip of the tongue they are for the most part elongated and pointed, and are called *filiform;* over the rest of the surface of the tongue, these are mixed with other, larger papillæ with broad ends and narrow bases, called *fungiform;* but towards its root there are a number of large papillæ, set in the shape of a V with its point backwards, each of which is like a fungiform papilla surrounded by a wall. These are the circumvallate papillæ (Fig. 53, *C.p.*). The larger of these papillæ have subordinate small ones upon their surfaces. They are very vascular, and they receive nervous filaments from two sources, the one the nerve called *glossopharyngeal,* the other the *fifth* nerve. The latter chiefly supplies the front of the tongue, the former its back and the adjacent part of the palate; and there is reason to believe that it is the latter region which is more especially the seat of the sense of taste.

The great majority of the sensations we call taste, however, are in reality complex sensations, into which smell and even touch largely enter.

13. The organ of the sense of SMELL is the delicate mucous membrane which lines a part of the nasal cavities, and is distinguished from the rest of the mucous membrane of these cavities—firstly, by possessing no cilia; secondly, by receiving its nervous supply from the olfactory, or first, pair of cerebral nerves, and not, like the rest of the mucous membrane, from the fifth pair.

Each nostril leads into a spacious nasal chamber, separated, in the middle line, from its fellow of the other side, by a partition, or *septum*, formed partly by cartilage and partly by bone, and continuous with that partition which separates the two nostrils one from the other. Below, each nasal chamber is separated from the cavity of the mouth by a floor, the bony palate (Figs. 54, 55); and when this bony palate comes to an end, the partition is continued down to the root of the tongue by a fleshy curtain,

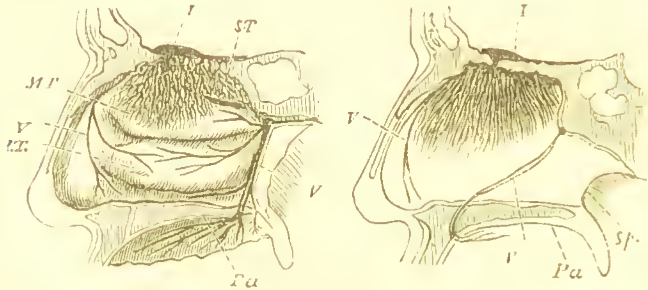

FIG. 54.

Vertical longitudinal sections of the nasal cavity.—The left-hand figure represents the outer wall of the right nasal cavity; the right-hand figure the left side of the middle partition or septum of the nose, which forms the right wall of the left nasal cavity. *I*, the olfactory nerve and its branches; *V*, branches of the fifth nerve; *Pa.* the palate which separates the nasal cavity from that of the mouth; *S.T.* the superior turbinal bone; *M.T.* the middle turbinal; *I.T.* the inferior turbinal. The letter *I* is placed in the cerebral cavity, and the partition on which the olfactory lobe rests, and through which the filaments of the olfactory nerves pass, is the cribriform plate.

the soft palate, which has been already described. The soft palate and the root of the tongue together, constitute, under ordinary circumstances, a transverse moveable partition between the mouth and the pharynx, and it will be observed that the opening of the larynx, the *glottis*, lies behind the partition; so that while the latter is complete, no passage of air can take place between the mouth and the pharynx. But above and behind the partition are the two hinder openings of the nasal cavities (which are called the *posterior nares*) separated by the termination of the septum; and through these wide openings the air passes, with great readiness, from the nostrils along the lower part of each nasal chamber to the glottis, or in the opposite direction. It is by means of the passages thus freely open to the air that we breathe, as we ordinarily do, with the mouth shut.

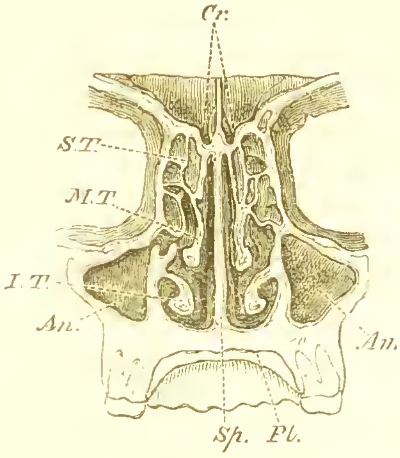

FIG. 55.

A transverse and vertical section of the osseous walls of the nasal cavity taken nearly through the letter *I* in the foregoing figure.—*Cr.* the cribriform plate; *S.T. M.T.* the chambered superior and middle turbinal bones on which and on the septum *Sp.* the filaments of the olfactory nerve are distributed; *I.T.* the inferior turbinal bone; *Pl.* the palate; *An.* the *Antrum* or chamber which occupies the greater part of the maxillary bone and opens into the nasal cavity.

Each nasal chamber rises, as a high vault, far above the level of the arch of the posterior nares—in fact, about as high as the depression of the root of the nose. The uppermost and front part of its roof, between the eyes, is formed by a delicate horizontal plate of bone, perforated like a sieve by a great many small holes, and thence called the *cribriform* plate (Fig. 55, *Cr.*). It is this plate (with the membranous structures which line its two faces) alone which, in this region, separates the cavity of the nose from that which contains the brain. The olfactory lobes, which are directly connected with, and indeed a part of, the brain, enlarge at their ends, and their broad extremities rest upon the upper side of the cribriform plate; sending immense numbers of delicate filaments, the olfactory nerves, through it to the olfactory mucous membrane (Fig. 54).

On each wall of the septum this mucous membrane forms a flat expansion, but, on the side walls of each nasal cavity, it follows the elevations and depressions of the inner surfaces of what are called the *upper* and *middle turbinal*, or spongy bones. These bones are called *spongy*, because the interior of each is occupied by air-cavities separated only by very delicate partitions, and communicating with the nasal cavities. Hence the bones, though massive-looking, are really exceedingly light and delicate, and fully deserve the appellation of spongy (Fig. 55).

There is a third light scroll-like bone distinct from these two, and attached to the maxillary bone, which is called the *inferior* turbinal, as it lies lower than the other two, and imperfectly separates the air-passages from the proper olfactory chamber (Fig. 54). It is covered by the ordinary ciliated mucous membrane of the nasal passages, and receives no filaments from the olfactory nerve (Fig. 54).

14. From the arrangements which have been described, it is clear that, under ordinary circumstances, the gentle inspiratory and expiratory currents will flow along the comparatively wide, direct passages afforded by so much of the nasal chamber as lies below the middle turbinal; and that they will hardly move the air enclosed in the narrow interspace between the septum and the upper and middle spongy bones, which is the proper olfactory chamber.

If the air currents are laden with particles of odorous matter, they can only reach the olfactory membrane by diffusing themselves into this narrow interspace; and, if there be but few of these particles, they will run the risk of not reaching the olfactory mucous membrane at all, unless the air in contact with it be exchanged for some of the odoriferous air. Hence it is that, when we wish to perceive a faint odour more distinctly, we sniff, or snuff up, the air. Each sniff is a sudden inspiration, the effect of which must reach the air in the olfactory chamber at the same time as, or even before, it affects that at the nostrils; and thus must tend to draw a little air out of that chamber from behind. At the same time, or immediately afterwards, the air sucked in at the nostrils, entering with a sudden vertical rush, part of it must tend to flow directly into the olfactory chamber, and replace that thus drawn out.

The loss of smell which takes place in the course of a severe cold may, in part, be due to the swollen state of the mucous membrane which covers the inferior turbinal bones, which thus impedes the passage of odoriferous air to the olfactory chamber.

15. The essential organ of the sense of HEARING consists, on each side, of two parts, the *membranous labyrinth*, and the *scala media of the cochlea*, both of which small organs are lodged in the midst of a dense and solid mass of bone (thence called *petrosal*), forming a part of the temporal bone, and entering into the base of the skull.

Each of these essential constituents of the organ of hearing is, substantially, a membranous bag filled with a fluid, and supported in fluid. In the interior of each, certain small, mobile, hard bodies are contained; and the ultimate filaments of the auditory nerves are so distributed upon the walls of the bags that their terminations must be knocked by the vibrations of these small hard bodies, should anything set them in motion. It is also quite possible that the vibrations of the fluid contents of the sacs may themselves suffice to affect the filaments of the auditory nerve; but, however this may be, any such effect must be greatly intensified by the co-operation of the solid particles.

In bathing in a tolerably smooth sea, on a rocky shore, the movement of the little waves, as they run backwards and forwards, is hardly felt by any one who lies down upon the beach; but, if the beach be sandy and gravelly, the pelting of the showers of little stones and sand, which are raised and let fall by each wavelet, makes a very definite impression on the nerves of the skin.

Now, the membrane on which the ends of the auditory nerves are spread out is virtually a sensitive beach, and waves which, by themselves, would not be felt, may be readily perceived if they suffice to raise and let fall hard particles.

In the membranous labyrinth these hard bodies are hair-like filaments, or minute particles of calcareous sand. The latter are called *otoconia*, or *otolithes*.

FIG. 56.

The delicate stiff filaments, *b*, which are set up on the inner walls of the ampullæ, *a*.

The epithelium (*a*, Fig. 56) which covers the termination of the nerves in the ampullæ (see § 16), is produced into long, stiff, slender, hair-like processes (*b*, Fig. 56), which are, of course, readily affected by any vibration of the endolymph, and communicate the impulse to the ends of the nerves. In the vestibular sac (§ 16), on the contrary, these hairs are scanty or absent, but the minute angular otoconia serve the same purpose.

In the scala media of the cochlea, minute, rod-like bodies, called the *fibres of Corti*, and which are peculiarly modified cells of the epithelial lining of the scala (§ 17), appear to serve the same object.

16. For simplicity's sake, the membranous labyrinth and the scala media have hitherto been spoken of as if they were simple bags; but this is not the case, each bag having a very curious and somewhat complicated form. (Figs. 57, 58.)

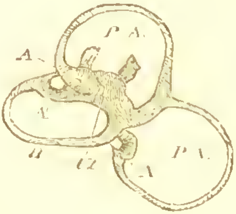

FIG. 57.

The membranous labyrinth, twice the natural size. *Ut.* the *Utriculus* or part of the vestibular sac, into which the semicircular canals open; *A A A* the ampullæ; *P.A.* anterior vertical semicircular canal; *P.V.* posterior vertical semicircular canal; *H.* horizontal semicircular canal.

Thus the *membranous labyrinth* (Fig. 57) has the figure of an oval *vestibular sac*, consisting of two parts, the one called *utriculus*, the other *sacculus hemisphericus*. The hoop-like *semicircular canals* open into the utriculus. They are three in number, and two, being vertical, are called the *anterior* (*P.A.*) and *posterior* (*P.V.*) *vertical semicircular canals;* while the third, lying outside, and horizontally, is termed the *external*, or *horizontal semicircular canal* (*H*). One end of each of these canals is dilated into what is called an *ampulla* (Fig. 57, *A*).

It is upon the walls of these ampullæ and those of the vestibular sac that the branches of the auditory nerve are distributed.

The fluid which fills the cavities of the semi-circular canals and utriculus is termed *endolymph.* That which separates these delicate structures from the bony chambers in which they are contained is the *perilymph.* Each of these fluids is little more than water.

17. In the *scala media** of the cochlea the primitive bag is drawn out into a long tube, which is coiled two and a half times on itself into a conical spiral, and lies in a much wider chamber of corre-

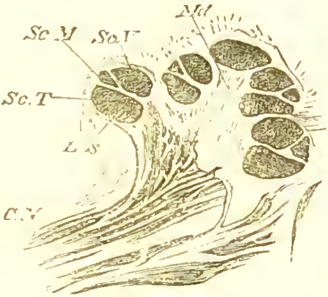

FIG. 58.

A section through the axis of the cochlea, magnified three diameters. *Sc.M.* scala media; *Sc.V.* scala vestibuli; *Sc.T.* scala tympani; *L.S.* lamina spiralis; *Md.* bony axis, or modiolus, round which the scalæ are wound; *C.N.* cochlear nerve.

sponding form, excavated in the petrous bone in such a way as to leave a central column of bony matter called the *modiolus.* The scala media has

* I employ this term as the equivalent of *canalis cochlearis.* The true nature and connexions of these parts have only recently been properly worked out, and the account now given will be found to be somewhat different from that in the former edition of this work. See particularly the explanation of Fig. 59.

a triangular transverse section (Fig. 58), being bounded above and below by the membranous walls, which converge internally and diverge externally. At their convergence, the walls are fastened to the edge by a thin plate of bone, the *lamina spiralis* (*L.S.* Fig. 58), which winds round the modiolus. The opposite ends of the walls of the scala media are fixed to the walls of the containing chamber, which thus becomes divided into two passages, which communicate at the summit of the spire, but are elsewhere separate. These two passages are called respectively the *scala tympani* and *scala vestibuli*, and are filled with perilymph.

The scala media, which thus lies between the other two scalæ, opens by a narrow duct into the sacculus hemisphericus, but at its opposite end terminates blindly. (Fig. 62.)

The fibres of the auditory nerve (*VII.* Fig. 59) are distributed to the whole length of the scala media. They enter it along the line of attachment to the lamina spiralis.

That wall of the scala media which separates it from the scala vestibuli is called the *membrane of Reissner.* The opposite wall, which separates it from the scala tympani, is the *basilar membrane.* The latter is very elastic, and on it rest the *fibres of Corti* (*C C'*), each of which is composed of two filaments joined at an angle. An immense number of these filaments are set side by side, with great regularity, throughout the whole length of the scala media, so that this organ presents almost the appearance of a key-board, if viewed from either the scala vestibuli or the scala tympani. The ends of the nerves have not yet been distinctly traced, but they probably come into close relation with these fibres,

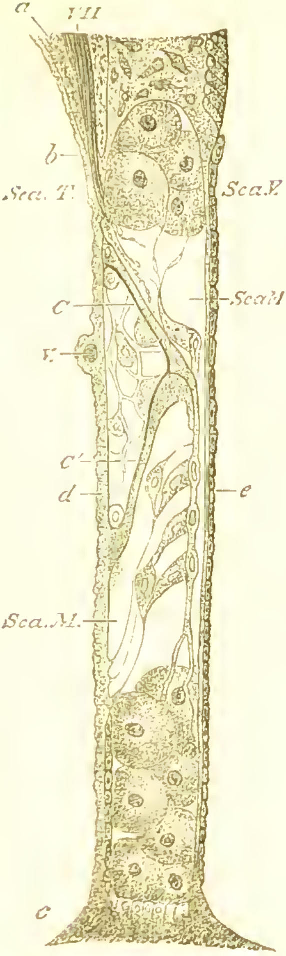

Fig. 59.

A section through that wall of the *scala media* of the cochlea which lies next to the scala tympani.—*a*. The inner wall, pillar, or modiolus of the bony cochlea; *c*, its outer wall; *Sca. T.* the cavity of the scala tympani; *Sca. V.* the cavity of the scala which are capable of being agitated by the slightest impulse.

18. These essential parts of the organ of hearing are lodged in chambers of the petrous part of the temporal bone. Thus the membranous labyrinth is contained in a cavity of corresponding form, of which that part which lodges the sac is termed the *vestibule*, and that which contains the semicircular canals, the *bony semicircular canals.* Further, it has been already seen that the scala media is contained in a spirally-coiled chamber, the *cochlea,* which it divides into two passages. Of these, one, the *scala vestibuli*, is so called because it opens directly into the vestibule; and hence it is that the perilymph fills these scalæ as well as the vestibule and semicircular canals, the whole being placed in communication by the wide aperture which leads from the vestibule into the scala vestibuli.

In the fresh state, the bony labyrinth, as this collection of cavities in the petrous bone is termed, is perfectly closed; but in the dry skull there are two wide openings, termed *fenestræ,* or windows, on its outer wall. Of these fenestræ, one, termed *ŏvalis* (the oval window), is situated in the wall of the vestibular cavity; the other, *rotunda* (the round window), behind and below this, is the open end of the *scala cochleæ.* In the fresh state, each of these windows

media; *Sca. M.* that part of the cavity of the scala media which lies between the basilar membrane and the membrane of Corti; *d,* the elastic *basilar* membrane which separates the scala media from the scala tympani; *V.* a vessel which lies in this cut through; *e,* the so-called membrane of Corti; *C C′*, the fibres of Corti; *VII.* the filaments of the auditory nerve. It is doubtful whether the membrane of Corti really has the extent and connexions given to it in this figure. The membrane of Reissner which separates the scala media from the scala vestibuli is not represented. If it were, the letters *Sca. V.* would be seen to lie in the scala media and not in the scala vestibuli.

or fenestræ is closed by a fibrous membrane, continuous with the periosteum of the bone.

The *fenestra rotunda* is closed only by membrane; but, fastened to the centre of the *fenestra ovalis*, so as to leave only a narrow margin, is an oval plate of bone, the base of the *stapes* or stirrup bone.

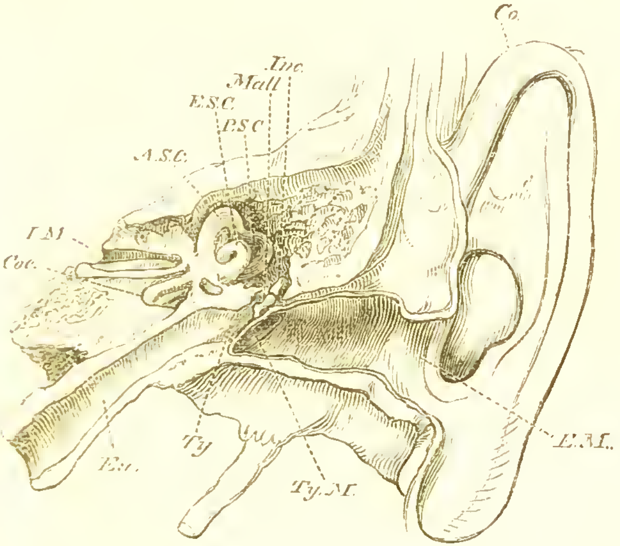

FIG. 60.

Transverse section through the side walls of the skull to show the parts of the ear.—*Co.* Concha or external ear; *E.M.* external auditory meatus; *Ty.M.* tympanic membrane; *Inc. Mall.* incus and malleus; *A.S.C. P.S.C. E.S.C.* anterior, posterior, and external semicircular canals; *Coc.* cochlea; *Eu.* Eustachian tube; *I.M.* internal auditory meatus, through which the auditory nerve passes to the organ of hearing.

19. The outer wall of the bony labyrinth is still far away from the exterior of the skull. Between it and the visible opening of the ear, in fact, are

placed in a straight line, first, the drum of the ear, or *tympanum;* secondly, the long external passage, or *meatus* (Fig. 57).

The drum of the ear and the external meatus would form one cavity, were it not that a delicate membrane, the tympanic membrane (*Ty.M.*) is tightly stretched in an oblique direction across the passage, so as to divide the comparatively small cavity of the drum from the meatus.

The membrane of the tympanum thus prevents any communication between the drum and the exterior, by means of the meatus, but such a communication is provided, though in a roundabout way, by the Eustachian tube (*Eu.* Fig. 60), which leads directly from the fore part of the drum inwards to the roof of the pharynx, where it opens.

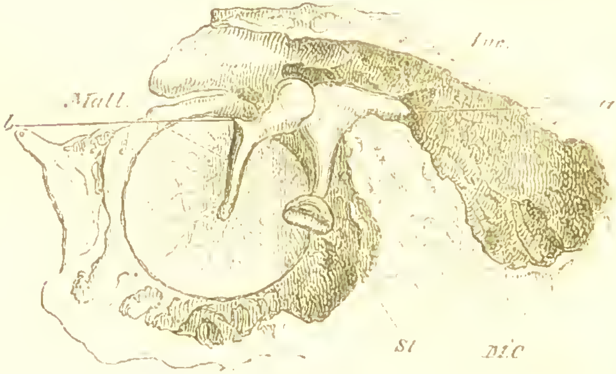

FIG. 61.

The membrane of the drum of the ear seen from the inner side, with the small bones of the ear; and the walls of the tympanum, with the air-cells in the mastoid part of the temporal bone.—*M.C.* Mastoid cells; *Mall.* malleus; *Inc.* incus; *St.* stapes; *a b*, lines drawn through the horizontal axis on which the malleus and incus turn.

20. Three small bones, the *auditory ossicles,* lie in the cavity of the tympanum. One of these is the *stapes,* a small bone shaped like a stirrup. The foot-plate of this bone is, as already mentioned, firmly fastened to the membrane of the *fenestra ovalis,* while its hoop projects outwards into the tympanic cavity (Fig. 62).

Another of these bones is the *malleus* (*Mall.* Figs. 60, 61, 62), or hammer-bone, a long process of which is similarly fastened to the inner side of the tympanic membrane (Fig. 62). The rounded surface

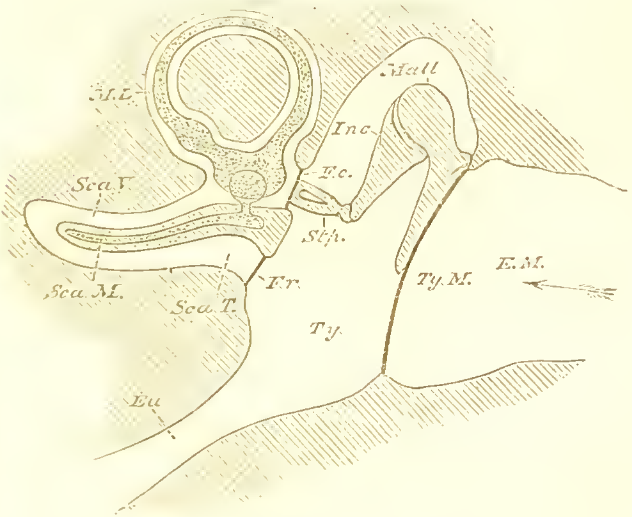

FIG. 62.

A diagram illustrative of the relative positions of the various parts of the ear.—*E.M.* External auditory meatus; *Ty.M.* tympanic membrane; *Ty.* tympanum; *Mall.* malleus; *Inc.* incus; *Stp.* stapes; *F.o.* fenestra ovalis; *F.r.* fenestra rotunda; *Eu.* Eustachian tube; *M.L.* membranous labyrinth, only one semicircular canal with its ampulla being represented; *Sca. V*, *Sca. T*, *Sca. M*, the scalæ of the cochlea, which is supposed to be unrolled.

of the head of the malleus fits into a corresponding pit in the other end of the third bone, the *incus* or anvil bone, which has two processes—one, horizontal, which rests upon a support afforded to it by the walls of the tympanum; while the other, vertical, descends almost parallel with the long process of the malleus, and articulates with the stapes, or rather with a little bone, the *os orbiculare,* which is united with the stapes (Figs. 61, 62).

The three bones thus form a chain between the fenestra ovalis and the tympanic membrane; and the whole series turns upon a horizontal axis, the two ends of which, formed by the horizontal process of the incus and the slender process of the malleus, rest in the walls of the tympanum. The general direction of this axis is represented by the line *a b* in Fig. 61, or by a line perpendicular to the plane of the paper, passing through the head of the malleus in Fig. 62. It follows, therefore, that whatever causes the membrane of the drum to vibrate backwards and forwards, must force the handle of the malleus to travel in the same way. This must cause a corresponding motion of the long process of the incus, the end of which must drag the stapes backwards and forwards. And, as this is fastened to the membrane of the fenestra ovalis, which is in contact with the perilymph, it must set this fluid vibrating throughout its whole extent, the thrustings in of the membrane of the fenestra ovalis being compensated by corresponding thrustings out of the membrane of the fenestra rotunda, and *vice versâ.*

The vibrations of the perilymph thus produced will affect the endolymph, and this the otolithes; by which, finally, the auditory nerves will be excited.

21. The membrane of the fenestra ovalis and

the tympanie membrane will neeessarily vibrate the more freely the looser they are, and the reverse. But there are two muscles—one, called the *stapedius*, which passes from the floor of the tympanum to the orbicular bone, and the other, the *tensor tympani*, from the front wall of the drum to the malleus. Each of the muscles when it contraets tightens the membranes in question, and restricts their vibrations; or, in other words, tends to eheck the effect of any eause which sets these membranes vibrating.

22. The outer extremity of the external meatus is surrounded by the *concha* or external ear (Fig. 60, *Co.*), a broad, peeuliarly-shaped, and, for the most part, eartilaginous plate, the general plane of which is at right angles with that of the axis of the auditory opening. The eoncha ean be moved in various directions by museles, whieh pass to it from the side of the head.

23. The manner in whieh the eomplex apparatus now described intermediates between the physical agent, whieh is the eondition of the sensation of sound, and the nervous expansion, the affection of which alone ean excite that sensation, must next be eonsidered.

All bodies which produee sound are in a state of vibration, and they eommunicate the vibrations of their own substanee to the air with whieh they are in contact, and thus throw that air into waves, just as a stick waved backwards and forwards in water throws the water into waves.

The aërial waves, produced by the vibrations of sonorous bodies, in part enter the external auditory passage, and in part strike upon the eoncha of the external ear and the outer surfaee of the head. It may be that some of the latter impulses are transmitted through the solid structure of the skull to the organ of hearing; but before they reach it they must, under ordinary circumstances, have become so scanty and weak, that they may be left out of consideration.

The aërial waves which enter the meatus all impinge upon the membrane of the drum and set it vibrating, stretched membranes taking up vibrations from the air with great readiness.

24. The vibrations thus set up in the membrane of the tympanum are communicated, in part, to the air contained in the drum of the ear, and, in part, to the malleus, and thence to the other auditory ossicles.

The vibrations communicated to the air of the drum impinge upon the inner wall of the tympanum, on the greater part of which, from its density, they can produce very little effect. Where this wall is formed by the membrane of the *fenestra rotunda*, however, the communication of motion must necessarily be greater.

The vibrations which are communicated to the malleus and the chain of ossicles may be of two kinds: vibrations of the particles of the bones, and vibrations of the bones as a whole. If a beam of wood, freely suspended, be very gently scratched with a pin, its particles will be thrown into a state of vibration, as will be evidenced by the sound given out, but the beam itself will not be moved. Again, if a strong wind blow against the beam, it will swing visibly, without any vibrations of its particles among themselves. On the other hand, if the beam be sharply struck with a hammer, it will not only give out a sound, showing that its particles are vibrating, but it will also swing, from the impulse given to its whole mass.

Under the last-mentioned circumstances, a blind man standing near the beam would be conscious of nothing but the sound, the product of molecular vibration, or invisible oscillation of the particles of the beam; while a deaf man, in the same position, would be aware of nothing but the visible oscillation of the beam as a whole.

25. Thus, to return to the chain of auditory ossicles, while it seems hardly to be doubted that, when the membrane of the drum vibrates, they are set vibrating both as a whole and in their particles, it depends upon subsidiary arrangements whether the large vibrations, or the minute ones, shall make themselves obvious to the auditory nerve, which is in the position of our deaf, or blind, man.

The evidence at present is in favour of the conclusion, that it is the vibrations of the bones, as a whole, which are the chief agents in transmitting the impulses of the aërial waves.

For, in the first place, the disposition of the bones and the mode of their articulation are very much against the transmission of molecular vibrations through their substance, while, on the other hand, they are extremely favourable to their vibration *en masse*. The long processes of the malleus and incus swing, like a pendulum, upon the axis furnished by the short processes of these bones; while the mode of connexion of the incus with the stapes, and of the latter with the edges of the fenestra ovalis, allows of free play, inwards and outwards, to that bone. And, in the second place, it is affirmed, as the result of experiments, that the bone called *columella*, which, in birds, takes the place of the chain of ossicles in man, does actually vibrate as a whole, and at the same rate as the membrane of the drum, when aërial vibrations strike upon the latter.

26. Thus, there is reason to believe that when the tympanic membrane is set vibrating, it causes the process of the malleus, which is fixed to it, to swing at the same rate; the head of the malleus consequently turns through a small arc on its pivot, the slender process. But the turning of the head of the malleus involves that of the head of the incus upon its pivot, the short process. In consequence, the long process of the incus swings through an arc as nearly as possible equal to that described by the handle of the malleus. The long process, however, is so fixed to the stapes that it cannot vibrate without, to a corresponding extent and at the same rate, pulling this out of, and pushing it in to, the fenestra ovalis. But every pull and push imparts a corresponding set of shakes to the perilymph, which fills the bony labyrinth and cochlea, external to the membranous labyrinth and scala media. These shakes are communicated to the endolymph and fluid of the scala media, and, by the help of the otolithes and the fibres of Corti, are finally converted into impulses, which act as irritants to the ends of the vestibular and cochlear divisions of the auditory nerve.

27. The difference between the functions of the membranous labyrinth (to which the vestibular nerve is distributed) and those of the cochlea, are, perhaps, not quite certainly made out, but the following conclusions are highly probable:—

The membranous labyrinth is an apparatus whereby sounds are appreciated and distinguished according to their intensity or quantity; but it does not afford any means of discriminating their qualities.

The vestibular nerve tells us that sounds are low or loud, but gives us no impression of tone, or melody, or harmony.

The cochlea, on the other hand, enables the mind to discriminate the quality rather than the quantity or intensity of sound. There is reason to believe that the excitement of any single filament of the cochlear nerve gives rise, in the mind, to a distinct musical impression; and that every fraction of a tone which a well-trained ear is capable of distinguishing is represented by its separate nerve-fibre. Thus, the scala media resembles a key-board, in function, as well as in appearance, the fibres of Corti being the keys, and the ends of the nerves representing the strings which the keys strike. If it were possible to irritate each of these nerve-fibres experimentally, we should be able to produce any musical tone, at will, in the sensorium of the person experimented upon, just as any note on a piano is produced by striking the appropriate key.

28. A tuning-fork may be set vibrating, if its own particular note, or one harmonic with it, be sounded in its neighbourhood. In other words, it will vibrate under the influence of a particular set of vibrations, and no others. If the vibrating ends of the tuning-fork were so arranged as to impinge upon a nerve, their repeated minute blows would at once excite this nerve.

Suppose that of a set of tuning-forks, tuned to every note and distinguishable fraction of a note in the scale, one were thus connected with the end of every fibre of the cochlear nerve; then any vibration communicated to the perilymph would affect the tuning-fork which could vibrate with it, while the rest would be absolutely, or relatively, indifferent to that vibration. In other words, the vibration would give rise to the sensation of one particular tone, and no other, and every musical interval would be represented by a distinct impression on the sensorium.

29. It is believed that the fibres of Corti are competent to perform the function of such tuning-forks; that each of them is set vibrating to its full strength by a particular kind of wave sent through the perilymph, and by no other; and that each affects a particular fibre of the cochlear nerve only.

The fibres of the cochlear nerve may be excited by internal causes, such as the varying pressure of the blood and the like. And in some persons such internal influences do give rise to veritable musical spectra, sometimes of a very intense character. But, for the appreciation of music produced external to us, we depend upon the intermediation of the scala media and its Cortian fibres.

30. It has already been explained that the *stapedius* and *tensor tympani* muscles are competent to tighten the membrane of the fenestra ovalis and that of the tympanum, and it is probable that they come into action when the sonorous impulses are too violent, and would produce too extensive vibrations of these membranes. They therefore tend to moderate the effect of intense sound, in much the same way that, as we shall find, the contraction of the circular fibres of the iris tends to moderate the effect of intense light in the eye.

The function of the Eustachian tube is, probably, to keep the air in the tympanum, or on the inner side of the tympanic membrane, of about the same tension as that on the outer side, which could not always be the case if the tympanum were a closed cavity.

LESSON IX.

THE ORGAN OF SIGHT.

1. In studying the organ of the sense of sight, the eye, it is needful to become acquainted, firstly, with the structure and properties of the sensory expansion in which the optic nerve terminates; secondly, with the physical agent of the sensation; thirdly, with the intermediate apparatus by which the physical agent is enabled to act upon the nervous expansion.

The ball of the eye is a globular body, moving freely in a chamber, the *orbit*, which is furnished to it by the skull. The optic nerve, the root of which is in the brain, leaves the skull by a hole at the back of the orbit, and enters the back of the globe of the eye, not in the middle, but on the inner, or nasal, side of the centre. It then spreads out on the inner surface of the wall of the globe of the eye, and enters a very delicate membrane, which extends forward nearly to the margin of the crystalline lens, varying in thickness from $\frac{1}{80}$th of an inch to less than half that amount, and is termed the *retina*. This retina is the only organ connected with sensory nervous fibres which can be affected, by any agent, in such a manner as to give rise to the sensation of light.

2. If the globe of the eye be cut in two, transversely, so as to divide it into an anterior and a

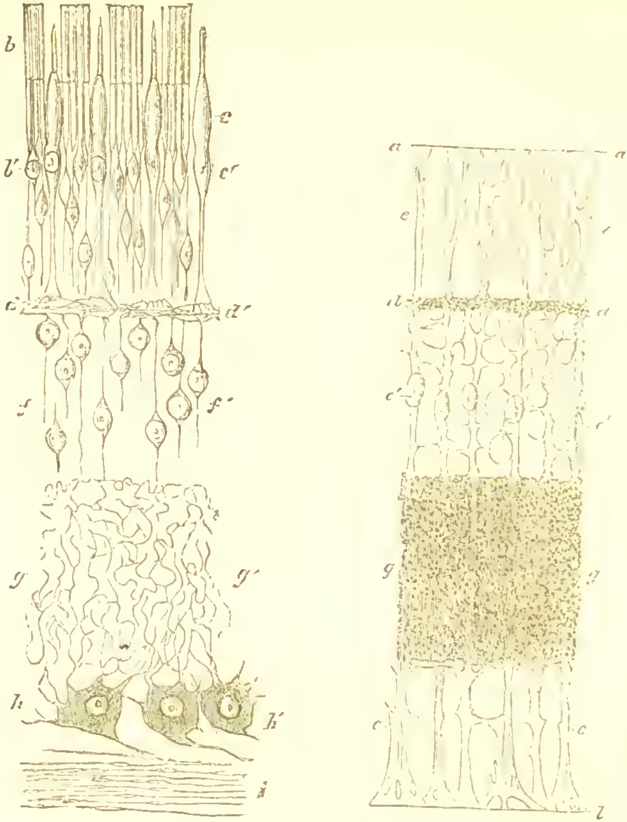

FIG. 63.

Diagrammatic views of the nervous (A) and the connective (B) elements of the retina, supposed to be separated from one another. A, the nervous structures—*b*, the rods; *c*, the cones; *b' c'* the granules of the outer layer, with which these are connected; *d d'*, interwoven very delicate nervous fibres, from which fine nervous filaments, bearing the inner granules, *f f'*, proceed towards the front surface; *g g'*, the continuation of these fine nerves, which become convoluted and interwoven with the processes of the ganglionic corpuscles, *h h'*; *i i*, the expansion of the fibres of the optic nerve B, the connective tissue—*a a*, external or posterior limiting membrane; *e e*, radial fibres passing to the internal or anterior limiting membrane; *e' e'*, nuclei; *d d*, the intergranular layer; *g g*, the molecular layer; *l*, the anterior limiting membrane.

Magnified about 250 diameters.

posterior half, the retina will be seen lining the concave wall of the posterior half as a membrane of great delicacy, and, for the most part, of even texture and smooth surface. But, exactly opposite the middle of the posterior wall, it presents a slight circular depression of a yellowish hue, the *macula lutea*, or yellow spot; and, at some distance from this, towards the inner, or nasal, side of the ball, is a radiating appearance, produced by the entrance of the optic nerve and the spreading out of its fibres into the retina.

3. A very thin vertical slice of the retina, in any region except the yellow spot and the entrance of the optic nerve, may be resolved into the structures represented separately in Fig. 63. The one of these (A) occupies the whole thickness of the section, and comprises its essential, or nervous, elements. The outer (or posterior) fourth, or rather less, of the thickness of these consists of a vast multitude of minute, rod-like, and conical bodies, ranged side by side, perpendicularly to the plane of the retina. This is the *layer of rods and cones* (*b c*). From the front ends of the rods and cones very delicate fibres pass, and in each is developed a granule-like body (*b′ c′*), which forms a part of what has been termed the *outer layer of granules.* It is probable that these fibres pass into and indeed form the close meshwork of very delicate nervous fibres which is seen at *d d′* (Fig. 63, A). From the anterior surface of this meshwork other fibres proceed, containing a second set of granules, which forms the *inner granular layer* (*f f′*). In front of this layer is a stratum of convoluted fine nervous fibres (*g g′*)—and anterior to this again numerous ganglionic corpuscles (*h h′*). Processes of these

ganglionic corpuscles extend, on the one hand, into the layer of convoluted nerve-fibres; and on the other are probably continuous with the stratum of fibres of the optic nerve (*i*).

These delicate nervous structures are supported by a sort of framework of connective tissue, which extends from an *inner* or *anterior limiting membrane* (*l*), which bounds the retina and is in contact with the vitreous humour, to an *outer* or *posterior limiting membrane*, which lies at the anterior ends of the rods and cones near the level of *b′ c′* in Fig. 63. Thus the framework is thinner than the nervous substance of the retina, and does not extend between the rods and cones, which lie between it and the pigment of the choroid coat (§ 16).

The fibres of the optic nerve spread out between the limiting membrane (*l*) and the ganglionic corpuscles (*h′*); and the vessels which enter along with the optic nerve ramify between the limiting membrane and the inner granules (*f f′*). Thus, not only the nervous fibres, but the vessels, are placed altogether in front of the rods and cones.

At the entrance of the optic nerve itself, the nervous fibres predominate, and the rods and cones are absent. In the yellow spot, on the contrary, the cones are abundant and close set, becoming at the same time longer and more slender, while rods are scanty, and are found only towards its margin. The layer of fibres of the optic nerve disappears, and all the other layers, except that of the cones, become extremely thin in the centre of the *macula lutea* (Fig. 64).

4. The most notable property of the retina is its power of converting the vibrations of ether, which constitute the physical basis of light, into a stimulus to the fibres of the optic nerve—which fibres, when

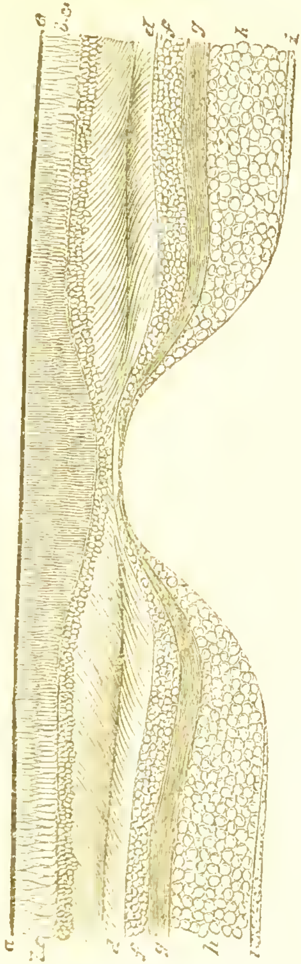

FIG. 64.

A diagrammatic section of the macula lutea, or yellow spot.—*a a*, the pigment of the choroid; *b*, *c*, rods and cones; *d d*, outer granular layer; *f f*, inner granular layer; *g g* molecular layer; *h h*, layer of ganglionic cells; *i i*, fibres of the optic nerve.

Magnified about 60 diameters.

excited, have the power of awakening the sensation of light in, or by means of, the brain. The sensation of light, it must be understood, is the work of the brain, not of the retina; for, if an eye be destroyed, pinching, galvanizing, or otherwise irritating the optic nerve, will still excite the sensation of light, because it throws the fibres of the optic nerve into activity; and their activity, however produced, brings about in the brain certain changes which give rise to the sensation of light.

Light, falling on the optic nerve, does not excite it; the fibres of the optic nerve, in themselves, are as blind as any other part of the body. But just as the delicate filaments of the ampullæ, or the otoconia of the vestibular sac, or the Cortian fibres of the cochlea, are contrivances for converting the delicate vibrations of the perilymph and endolymph into impulses which can excite the auditory nerves, so the structures in the retina appear to be adapted to convert the infinitely more delicate pulses of the luminiferous ether into stimuli of the fibres of the optic nerve.

5. The sensibility of the different parts of the retina to light varies very greatly. The point of entrance of the optic nerve is absolutely blind, as may be proved by a very simple experiment. Close the left eye, and look steadily with the right at the cross on the page, held at ten or twelve inches' distance.

The black dot will be seen quite plainly, as well as the cross. Now, move the book slowly towards the eye, which must be kept steadily fixed upon the cross; at a certain point the dot will disappear, but, as the book is brought still closer, it will come into view again. It results from optical principles that, in the first position of the book, the figure of the dot falls between that of the cross (which throughout lies upon the yellow spot) and the entrance of the optic nerve: while, in the second position, it falls on the entrance of the optic nerve itself; and, in the third, inside that point. So long as the image of the spot rests upon the entrance of the optie nerve, it is not perceived, and hence this region of the retina is called the *blind spot.*

6. The impression made by light upon the retina not only remains during the whole period of the direct action of the light, but has a certain duration of its own, however short the time during which the light itself lasts. A flash of lightning is, practically, instantaneous, but the sensation of light produced by that flash endures for an appreciable period. It is found, in fact, that a luminous impression lasts for about one-eighth of a second; whence it follows, that if any two luminous impressions are separated by a less interval, they are not distinguished from one another.

For this reason a "Catherine-wheel," or a lighted stick turned round very rapidly by the hand, appears as a circle of fire; and the spokes of a coach wheel at speed are not separately visible, but only appear as a sort of opacity, or film, within the tire of the wheel.

7. The excitability of the retina is readily exhausted. Thus, looking at a bright light, rapidly renders the part of the retina on which the light falls, insensible; and on looking from the bright light towards a moderately-lighted surface, a dark spot, arising from a temporary blindness of the

retina in this part, appears in the field of view. If the bright light be of one colour, the part of the retina on which it falls becomes insensible to rays of that colour, but not to the other rays of the spectrum. This is the explanation of the appearance of what are called *complementary colours.* For example, if a bright red wafer be stuck upon a sheet of white paper, and steadily looked at for some time with one eye, when the eye is turned aside to the white paper a greenish spot will appear, of the size and shape of the wafer. The red image has, in fact, fatigued the part of the retina on which it fell for red light, but has left it sensitive to the remaining coloured rays of which white light is composed. So that, when white light falls upon this part, the red rays in the white light have no effect, and the result of the operation of the others is a greenish hue. If the wafer be *green,* the *complementary image,* as it is called, is *red.*

8. In some persons, the retina appears to be affected in one and the same way by rays of light of various colours, or even of all colours. Such *colour-blind* persons are unable to distinguish between the leaves of a cherry-tree and its fruit by the colour of the two, and see no difference between blue and yellow cloth.

This peculiarity is simply unfortunate for most people, but it may be dangerous if unknowingly possessed by railway guards or sailors. It probably arises either from a defect in the retina, which renders that organ unable to respond to different kinds of luminous vibrations, or it may proceed from some unusual absorptive power of the humours of the eye.

9. The sensation of light may be excited by other

causes than the impact of the vibrations of the luminiferous ether upon the retina. Thus, an electric shock sent through the eye, gives rise to the appearance of a flash of light: and pressure on any part of the retina produces a luminous image, which lasts as long as the pressure, and is called a *phosphene*. If the point of the finger be pressed upon the outer side of the ball of the eye, a luminous image—which, in my own case, is dark in the centre, with a bright ring at the circumference (or, as Newton described it, like the "eye" in a peacock's tail)—is seen; and this image lasts as long as the pressure is continued. Most persons, again, have experienced the remarkable display of subjective fireworks which follows a heavy blow upon the eyes, produced by a fall from a horse, or by other methods well known to English youth.

It is doubtful, however, whether these effects of pressure, or shock, really arise from the excitation of the retina proper, or whether they are not rather the result of the violence done to the fibres of the optic nerve apart from the retina.

10. The last paragraph raises a distinction between the "fibres of the optic nerve" and the "retina" which may not have been anticipated, but which is of much importance.

We have seen that the fibres of the optic nerve ramify in the inner fourth of the thickness of the retina, while the layer of rods and cones forms its outer fourth. The light, therefore, must fall first upon the fibres of the optic nerve, and, only after traversing them, can it reach the rods and cones. Consequently, if the fibrillæ of the optic nerve themselves are capable of being affected by light, the rods and cones can only be some sort of supplementary optical apparatus. But, in fact, it is the rods and cones which are affected by light, while the fibres of the optic nerve are themselves insensible to it. The evidence on which this statement rests is—

a. The blind spot is full of nervous fibres, but has no cones or rods.

b. The yellow spot, where the most acute vision is situated, is full of close-set cones, but has no nerve fibres.

c. If you go into a dark room with a single small bright candle, and, looking towards a dark wall, move the light up and down, close to the outer side of one eye, so as to allow the light to fall very obliquely into the eye, one of what are called *Purkinje's figures* is seen. This is a vision of a series of diverging, branched, red lines on a dark field, and in the interspace of two of these lines is a sort of cup-shaped disk. The red lines are the retinal blood-vessels, and the disk is the yellow spot. As the candle is moved up and down, the red lines shift their position, as shadows do when the light which throws them changes its place.

Now, as the light falls on the inner face of the retina, and the images of the vessels to which it gives rise shift their position as it moves, whatever perceives these images must needs lie on the other, or outer, side of the vessels. But the fibres of the optic nerve lie among the vessels, and the only retinal structures which lie outside them are the granular layers and the rods and cones.

d. Just as, in the skin, there is a limit of distance within which two points give only one impression; so there is a minimum distance by which two points of light falling on the retina must be separated in order to appear as two. And this distance corresponds pretty well with the diameter of the cones.

Thus it would appear that these remarkable structures, set upon the outer surface of the retina, with their ends turned towards the light, are like so many finger-points, endowed with a touch delicate enough to feel the luminous vibrations.

11. The physical agent which gives rise to vision is *light*, which is now conceived to be a very attenuated fluid, the ether, vibrating in a particular way. The properties of this physical agent, and the principles of optics, must be studied elsewhere. At present it is only necessary to advert to some facts, of which every one can assure himself by simple experiments. An ordinary spectacle glass is a transparent body denser than the air, and convex on both sides. If this *lens* be held at a certain distance from a screen or wall in a dark room, and a lighted candle be placed on the opposite side of it, it will be easy to adjust the distances of candle, lens, and wall, so that an image of the flame of the candle, upside down, shall be thrown upon the wall.

12. The spot on which the image is formed is called a *focus*. If the candle be now brought nearer to the lens, the image on the wall will enlarge, and grow blurred and dim, but may be restored to brightness and definition by moving the lens further from the wall. But if, when the new adjustment has taken place, the candle be moved away from the lens, the image will again become confused, and, to restore its clearness, the lens will have to be brought nearer the wall.

Thus a convex lens forms a distinct picture of luminous objects, but only at the focus on the side of the lens opposite to the object; and that focus is nearer when the object is distant, and further off when it is near.

13. Suppose, however, that, leaving the candle unmoved, a lens with more convex surfaces is substituted for the first, the image will be blurred, and the lens will have to be moved nearer the wall to give it definition. If, on the other hand, a lens with less convex surfaces is substituted for the first, it must be moved further from the wall to attain the same end.

In other words, other things being alike, the more convex the lens the nearer its focus; the less convex, the further off its focus.

If the lens were elastic, pulling it at the circumference would render it flatter, and thereby lengthen its focus; while, when let go again, it would become more convex, and of shorter focus.

Any material more refractive than the medium in which it is placed, if it have a convex surface, causes the rays of light which pass through the less refractive medium to that surface to converge towards a focus. If a watch-glass be fitted into one side of a box, and the box be then filled with water, a candle may be placed at such a distance outside the watch-glass, that an image of its flame shall fall on the opposite wall of the box. If, under these circumstances, a doubly convex lens of glass were introduced into the water in the path of the rays, it would act (though less powerfully than if it were in air) in bringing the rays more quickly to a focus, because glass refracts light more strongly than water does.

A *camera obscura* is a box, into one side of which a lens is fitted, so as to be able to slide backwards and forwards, and thus throw distinct images of bodies, at various distances, on the screen at the back of the box. Hence the arrangement just described might be termed a *water camera.*

14. The intermediate organs by means of which the physical agent of vision, light, is enabled to act upon the expansion of the optic nerve, comprise three kinds of apparatus: (*a*) A "water camera," the eyeball; (*b*) muscles for moving the eyeball; (*c*) organs for protecting the eyeball, viz. the eyelids, with their lashes, glands, and muscles; the conjunctiva; and the lachrymal gland and its ducts.

The *eyeball* is composed, in the first place, of a tough, firm, spheroidal case consisting of connective tissue, the greater part of which is white and opaque, and is called the *sclerotic* (*Scl.* Fig. 65). In front, however, this fibrous capsule of the eye, though it does not change its essential character, becomes transparent, and receives the name of the *cornea* (*Cn.* Fig. 65). The corneal portion of the case of the eyeball is more convex than the sclerotic portion, so that the whole form of the ball is such as would be produced by cutting off a segment from the front of a spheroid of the diameter of the sclerotic, and replacing this by a segment cut from a smaller, and consequently more convex, spheroid.

15. The corneo-sclerotic case of the eye is kept in shape by what are termed the *humours*—watery or semi-fluid substances, one of which, the *aqueous* humour, distends the corneal chamber of the eye, while the other, the *vitreous*, keeps the sclerotic chamber full.

The two humours are separated by the very beautiful, transparent, doubly-convex *crystalline* *lens* (*Cry.* Fig. 65), denser, and capable of refracting light more strongly, than either of the humours. The crystalline lens is composed of fibres having a somewhat complex arrangement, and is highly elastic. It is more convex behind than in front, and

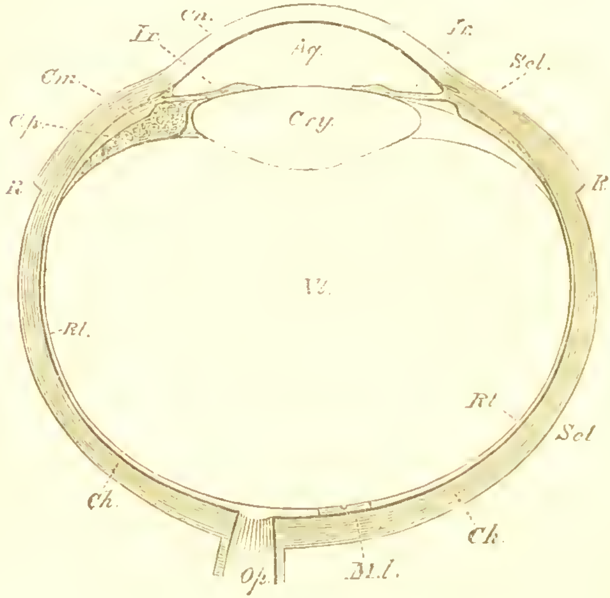

FIG. 65.

Horizontal section of the eyeball.—*Scl.* the sclerotic coat; *Cn.* the cornea; *R.* the attachments of the tendons of the recti muscles; *Ch.* the choroid; *C.p.* the ciliary processes; *C.m.* the ciliary muscle; *Ir.* the iris; *Aq.* the aqueous humour; *Cry.* the crystalline lens; *Vt.* the vitreous humour; *Rt.* the retina; *Op.* the optic nerve; *M.l.* the yellow spot. The section has passed through a ciliary process on the left side, and between two ciliary processes on the right.

it is kept in place by a delicate, but at the same time strong and elastic, membranous frame or *sus-*

pensory ligament, which extends from the edges of the lens to what are termed the *ciliary processes* of the choroid coat (*C.p.* Fig. 65).

16. This *choroid coat* (*Ch.* Fig. 65) is a highly vascular membrane, in close contact with the sclerotic externally, and lined, internally, by a layer of small polygonal bodies containing much pigmentary matter, called *pigment cells.* These pigment cells are separated from the vitreous humour by the retina only. The rods and cones of the latter are in immediate contact with them. The choroid lines every part of the sclerotic, except where the optic nerve enters it, at a point below, and to the inner side of the centre of the back of the eye; but when it reaches the front part of the sclerotic, its inner surface becomes raised up into a number of longitudinal ridges, with intervening depressions, terminating within and in front by rounded ends, but passing, externally, into the iris. These ridges are the above mentioned ciliary processes (*C.p.* Fig. 65).

17. The *iris* itself (*Ir.* Fig. 65) is, as has already been said, a curtain with a round hole in the middle, provided with circular and radiating unstriped muscular fibres; and capable of having its central aperture enlarged or diminished by the action of these fibres, the contraction of which, unlike that of other unstriped muscular fibres, is extremely rapid. The edges of the iris are firmly connected with the capsule of the eye, at the junction of the cornea and sclerotic, by the connective tissue which enters into the composition of the so-called *ciliary ligament.* Unstriped muscular fibres, having the same attachment in front, spread backwards on to the outer surface of the choroid, constituting the *ciliary muscle* (*C.m.* Fig. 65). If these fibres contract, it

is obvious that they will pull the choroid forwards; and as the frame, or suspensory ligament of the lens, is connected with the ciliary processes (which simply form the anterior termination of the choroid), this pulling forward of the choroid comes to the same thing as a relaxation of the tension of that suspensory ligament, which, as I have just said, like the lens itself, is highly elastic.

The iris does not hang down perpendicularly into the space between the front face of the crystalline lens and the posterior surface of the cornea, which is filled by the aqueous humour, but applies itself very closely to the anterior face of the lens, so that hardly any interval is left between the two (Figs. 65, 66).

18. The eyeball, the most important constituents of which have now been described, is, in principle, a camera of the kind described above—a water camera. That is to say, the sclerotic answers to the box, the cornea to the watch-glass, the aqueous and vitreous humours to the water filling the box, the crystalline to the glass lens, the introduction of which was imagined. The back of the box corresponds with the retina.

But further, in an ordinary camera obscura, it is found desirable to have what is termed a *diaphragm* (that is, an opaque plate with a hole in its centre) in the path of the rays, for the purpose of moderating the light and cutting off the marginal rays which, owing to certain optical properties of spheroidal surfaces, give rise to defects in the image formed at the focus.

In the eye, the place of this diaphragm is taken by the iris, which has the peculiar advantage of being self-regulating; dilating its aperture, and admitting more light when the light is weak; but contracting its aperture and admitting less light when the illumination is strong.

19. In the water camera, constructed according to the description given above, there is the defect that no provision exists for adjusting the focus to the varying distances of objects. If the box were so made that its back, on which the image is supposed to be thrown, received distinct images of very distant objects, all near ones would be indistinct. And if, on the other hand, it were fitted to receive the image of near objects, at a given distance, those of either nearer, or more distant, bodies would be blurred and indistinct. In the ordinary camera this difficulty is overcome by sliding the lenses in and out, a process which is not compatible with the construction of our water camera. But there is clearly one way, among many, in which this adjustment might be effected—namely, by changing the glass lens; putting in a less convex one when more distant objects had to be pictured, and a more convex one when the images of nearer objects were to be thrown upon the back of the box.

But it would come to the same thing, and be much more convenient, if, without changing the lens, one and the same lens could be made to alter its convexity. This is what actually is done in the adjustment of the eye to distances.

20. The simplest way of experimenting on the *adjustment of the eye* is to stick two stout needles upright into a straight piece of wood, not exactly, but nearly in the same straight line, so that, on applying the eye to one end of the piece of wood, one needle (*a*) shall be seen about six inches off,

and the other (*b*) just on one side of it at twelve inches' distance.

If the observer look at the needle *b* he will find that he sees it very distinctly, and without the least sense of effort; but the image of *a* is blurred and more or less double. Now, let him try to make this blurred image of the needle *a* distinct. He will find he can do so readily enough, but that the act is accompanied by a sense of fatigue. And in proportion as *a* becomes distinct, *b* will become blurred. Nor will any effort enable him to see *a* and *b* distinctly at the same time.

21. Multitudes of explanations have been given of this remarkable power of adjustment, but it is only within the last few years that the problem has been solved, by the accurate determination of the nature of the changes in the eye which accompany the act. When the flame of a taper is held near, and a little on one side of, a person's eye, any one looking into the eye from a proper point of view, will see three images of the flame, two upright and one inverted. One upright figure is reflected from the front of the cornea, which acts as a convex mirror. The second proceeds from the front of the crystalline lens, which has the same effect; while the inverted image proceeds from the posterior face of the lens, which, being convex backwards, is, of course, concave forwards, and acts as a concave mirror.

Suppose the eye to be steadily fixed on a distant object, and then adjusted to a near one in the same line of vision, the position of the eyeball remaining unchanged. Then the upright image reflected from the surface of the cornea, and the inverted image from the back of the lens, will remain unchanged, though it is demonstrable that their size or apparent position must change if either the cornea, or the back of the lens, alter either their form, or their position. But the second upright image, that reflected by the front face of the lens, changes both its size and its position; and that in such a manner as to prove that the front face of the lens has become more convex. The change of form of the lens is, in fact, that represented in Fig. 66.

These may be regarded as the *facts of adjustment* with which all explanations of that process must accord. They at once exclude the hypotheses (1) that adjustment is the result of the compression

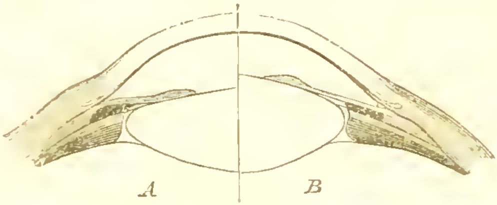

FIG. 66.

Illustrates the change in the form of the lens when adjusted—*A* to distant, *B* to near objects.

of the ball of the eye by its muscles, which would cause a change in the form of the cornea; (2) that adjustment results from a shifting of the lens bodily, for its hinder face does not move; (3) that it results from the pressure of the iris upon the front face of the lens, for under these circumstances the hinder face of the lens would not remain stationary. This last hypothesis is further negatived by the fact that adjustment takes place equally well when the iris is absent.

One other explanation remains, which is, in all probability, the true one, though not altogether devoid of difficulties. The lens, which is very elastic, is kept habitually in a state of tension by the elasticity of its suspensory ligament, and consequently has a flatter form than it would take if left to itself. If the ciliary muscle contracts, it must, as has been seen, relax that ligament, and thereby diminish its elastic tension upon the lens. The lens, consequently, will become more convex, returning to its former shape when the ciliary muscle ceases to contract, and allows the choroid to return to its ordinary place.

If this be the true explanation of adjustment, the sense of effort we feel must arise from the contraction of the ciliary muscle.

22. Adjustment can take place only within a certain range, which admits of great individual variations. As a rule, no object which is brought within less than about ten inches of the eye can be seen distinctly without effort.

But many persons are born with the surface of the cornea more convex than usual, or with the refractive power of the eye increased in some other way; while, very generally, as age draws on, the cornea flattens. In the former case, objects at ordinary distances are seen indistinctly, because these images fall not on the retina, but in front of it; while, in the latter, the same indistinctness is the result of the rays of light striking upon the retina before they have been brought to a focus. The defect of the former, or short-sighted people, is amended by wearing concave glasses, which cause the rays to diverge; of the latter, or long-sighted people, by wearing convex glasses, which make the rays converge.

23. The *muscles* which move the eyeball are altogether six in number—four straight muscles, or *recti,* and two oblique muscles, the *obliqui.* The straight muscles are attached to the back of the orbit, round the edges of the hole through which the optic nerve passes, and run straight forward to their insertions into the sclerotic—one, the *superior*

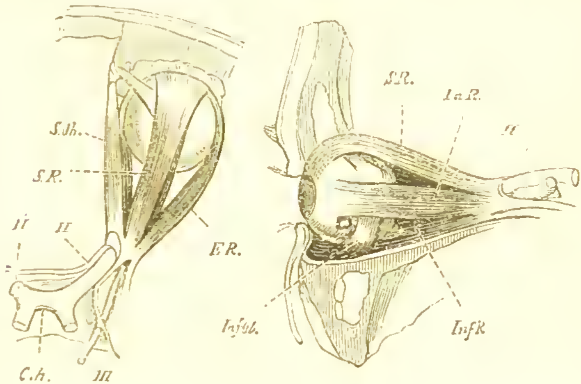

FIG. 67.

The muscles of the eyeball viewed from above and from the outer side.—*S.R.* the superior rectus; *Inf. R.* the inferior rectus; *E.R.* the external rectus; *In.R.* the internal rectus; *S.Ob.* the superior oblique; *Inf Ob.* the inferior oblique; *Ch.* the chiasma of the optic nerves *(II.)*; *III.* the third nerve which supplies all the muscles except the superior oblique and the external rectus.

rectus, in the middle line above; one, the *inferior,* opposite it below; and one half-way on each side, the *external* and *internal recti.* The eyeball is completely imbedded in fat behind and laterally; and these muscles turn it as on a cushion, the superior rectus inclining the axis of the eye upwards, the inferior downwards, the external outwards, the internal inwards.

The two oblique muscles are both attached on the outer side of the ball, and rather behind its centre; and they both pull in a direction from the point of attachment towards the inner side of the orbit—the lower, because it arises here; the upper, because, though it arises along with the recti from the back of the orbit, yet, after passing forwards and becoming tendinous at the upper and inner corner of the orbit, it traverses a pulley-like loop of ligament, and then turns downwards and outwards to its insertion. The action of the oblique muscles is somewhat complicated, but their general tendency is to roll the eyeball on its axis, and pull it a little forward and inward.

24. The *eyelids* are folds of skin containing thin plates of cartilage, and fringed at their edges with hairs, the *eyelashes*, and with a series of small glands called *Meibomian*. Circularly disposed fibres of striped muscle lie beneath the integuments of the eyelids, and constitute the *orbicularis* muscle which shuts them. The upper eyelid is raised by a special muscle, the *levator* of the upper lid, which arises at the back of the orbit and runs forwards to end in the lid.

The lower lid has no special depressor.

25. At the edge of the eyelids the integument becomes continuous with a delicate, vascular, and highly nervous mucous membrane, the *conjunctiva*, which lines the interior of the lids and the front of the eyeball, its epithelial layer being even continued over the cornea. The numerous small ducts of a gland which is lodged in the orbit, on the outer side of the ball (Fig. 68), the *lachrymal gland*, constantly pour its watery secretion into the interspace between the conjunctiva lining the upper eyelid and

that covering the ball. On the inner side of the eye is a reddish fold, the *caruncula lachrymalis*, a sort of rudiment of the third eyelid which is to be found

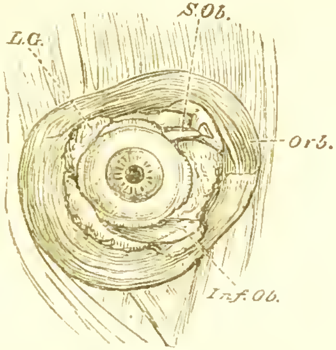

FIG. 68.

A front view of the eye dissected to show, *Orb.*, the orbicular muscle of the eyelids; the pulley and insertion of the superior oblique, *S.Ob.*, and the inferior oblique, *Inf.Ob.*; *L.G.* the lachrymal gland.

in many animals. Above and below, the edge of each eyelid presents a minute aperture (the *punctum lachrymale*), the opening of a small canal.

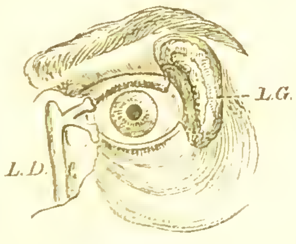

FIG. 69.

A front view of the eye, with the eyelids.—Lachrymal gland, *L.G.*, and Lachrymal duct, *L.D.*

The canals from above and below converge and open into the *lachrymal sac*, the upper blind end of a duct (*L.D.* Fig. 69) which passes down from the orbit to the nose, opening below the inferior turbinal bone (Fig. 34, *h*). It is through this system of canals that the conjunctival mucous membrane is continuous with that of the nose; and it is by them that the secretion of the lachrymal canal is ordinarily carried away as fast as it forms.

But, under certain circumstances, as when the conjunctiva is irritated by pungent vapours, or when painful emotions arise in the mind, the secretion of the lachrymal gland exceeds the drainage power of the lachrymal duct, and the fluid, accumulating between the lids, at length overflows in the form of tears.

LESSON X.

THE COALESCENCE OF SENSATIONS WITH ONE ANOTHER AND WITH OTHER STATES OF CONSCIOUSNESS.

1. In explaining the functions of the sensory organs, I have hitherto confined myself to describing the means by which the physical agent of a sensation is enabled to irritate a given sensory nerve; and to giving some account of the simple sensations which are thus evolved.

Simple sensations of this kind are such as might be produced by the irritation of a single nerve fibre, or of several nerve fibres by the same agent. Such are the sensations of contact, of warmth, of sweetness, of an odour, of a musical note, of whiteness, or redness.

But very few of our sensations are thus simple. Most of even those which we are in the habit of regarding as simple, are really compouuds of different sensations, or of sensations with ideas, or with judgments. For example, in the preceding cases, it is very difficult to separate the sensation of contact from the judgment that something is touching us; of sweetness, from the idea of something in the mouth; of sound or light, from the judgment that something outside us is shining, or sounding.

2. The sensations of smell are those which are least complicated by accessories of this sort. Thus,

particles of musk diffuse themselves with great rapidity through the nasal passages, and give rise to the sensation of a powerful odour. But beyond a broad notion that the odour is in the nose, this sensation is unaccompanied by any ideas of locality and direction. Still less does it give rise to any conception of form, or size, or force, or of succession, or contemporaneity. If a man had no other sense than that of smell, and musk were the only odorous body, he could have no sense of *outness*—no power of distinguishing between the external world and himself.

3. Contrast this with what may seem to be the equally simple sensation obtained by drawing the finger along the table, the eyes being shut. This act gives one the sensation of a flat hard surface outside oneself, which appears to be just as simple as the odour of musk, but is really a complex state of feeling compounded of—

(*a*) Pure sensations of contact.

(*b*) Pure muscular sensations of two kinds,—the one arising from the resistance of the table, the other from the actions of those muscles which draw the finger along.

(*c*) Ideas of the order in which these pure sensations succeed one another.

(*d*) Comparisons of these sensations and their order, with the recollection of like sensations similarly arranged, which have been obtained on previous occasions.

(*e*) Recollections of the impressions of extension, flatness, &c. made on the organ of vision when these previous tactile and muscular sensations were obtained.

Thus, in this case, the only pure sensations are those of contact and muscular action. The greater part of what we call the sensation is a complex mass of present and recollected ideas and judgments.

4. Should any doubt remain that we do thus mix up our sensations with our judgments into one indistinguishable whole, shut the eyes as before, and instead of touching the table with the finger, take a round lead pencil between the fingers, and draw that along the table. The "sensation" of a flat hard surface will be just as clear as before; and yet all that we touch is the round surface of the pencil, and the only pure sensations we owe to the table are those afforded by the muscular sense. In fact, in this case, our "sensation" of a flat hard surface is entirely a judgment based upon what the muscular sense tells us is going on in certain muscles.

A still more striking case of the tenacity with which we adhere to complex judgments, which we conceive to be pure sensations, and are unable to analyse otherwise than by a process of abstract reasoning, is afforded by our sense of roundness.

Any one taking a marble between two fingers will say that he feels it to be a single round body; and he will probably be as much at a loss to answer the question how he knows that it is round, as he would be if he were asked how he knows that a scent is a scent.

Nevertheless, this notion of the roundness of the marble is really a very complex judgment, and that it is so may be shown by a very simple experiment. If the index and middle fingers be crossed, and the marble placed between them, so as to be in contact with both, it is utterly impossible to avoid the belief that there are two marbles instead of one. Even looking at the marble, and seeing that there is only one, does not weaken the apparent proof derived from touch that there are two.*

The fact is, that our notions of singleness and roundness are, really, highly complex judgments based upon a few simple sensations; and when the ordinary conditions of those judgments are reversed, the judgment is also reversed.

With the index and middle fingers in their ordinary position, it is of course impossible that the outer sides of each should touch opposite surfaces of one spheroidal body. If, in the natural and usual position of the fingers, their outer surfaces simultaneously give us the impression of a spheroid (which itself is a complex judgment), it is in the nature of things that there must be two spheroids. But, when the fingers are crossed over the marble, the outer side of each finger is really in contact with a spheroid; and the mind, taking no cognizance of the crossing, judges in accordance with its universal experience, that two spheroids, and not one, give rise to the sensations which are perceived.

5. Phenomena of this kind are not uncommonly called *delusions of the senses;* but there is no such thing as a fictitious, or delusive, sensation. A sensation must exist to be a sensation, and if it exists it is real and not delusive. But the judgments we form respecting the causes and conditions of the sensations of which we are aware, are very often erroneous and delusive enough; and such judgments may be brought about in the domain of every sense,

* A ludicrous form of this experiment is to apply the crossed fingers to the end of the nose, when it at once appears double; and, in spite of the absurdity of the conviction, the mind cannot expel it, so long as the sensations last.

either by artificially contrived combinations of sensations, or by the influence of unusual conditions of the body itself. The latter give rise to what are called *subjective sensations*.

Mankind would be subject to fewer delusions than they are, if they constantly bore in mind their liability to false judgments, due to unusual combinations, either artificial or natural, of true sensations. Men say, "I felt," "I heard," "I saw" such and such a thing, when, in ninety-nine cases out of a hundred, what they really mean is, that they judge that certain sensations of touch, hearing, or sight, of which they were conscious, were caused by such and such things.

6. Among *subjective sensations* within the domain of touch, are the feelings of creeping and prickling of the skin, which are not uncommon in certain states of the circulation. The subjective evil smells and bad tastes which accompany some diseases are very probably due to similar disturbances in the circulation of the sensory organs of smell and taste.

Many persons are liable to what may be called *auditory spectra*—music of various degrees of complexity sounding in their ears, without any external cause, while they are wide awake. I know not if other persons are similarly troubled, but in reading books written by persons with whom I am acquainted, I am sometimes tormented by hearing the words pronounced in the exact way in which these persons would utter them, any trick or peculiarity of voice, or gesture, being, also, very accurately reproduced. And I suppose that every one must have been startled, at times, by the extreme distinctness with which his thoughts have embodied themselves in apparent voices.

The most wonderful exemplifications of subjective sensation, however, are afforded by the organ of sight.

Any one who has witnessed the sufferings of a man labouring under *delirium tremens* (a disease produced by excessive drinking), from the marvellous distinctness of his visions, which sometimes take the form of devils, sometimes of creeping animals, but almost always of something fearful or loathsome, will not doubt the intensity of subjective sensations in the domain of vision.

7. But that illusive visions of great distinctness should appear, it is not necessary for the nervous system to be thus obviously deranged. People in the full possession of their faculties, and of high intelligence, may be subject to such appearances, for which no distinct cause can be assigned. The best illustration of this is the famous case of Mrs. A. given by Sir David Brewster, in his "Natural Magic," the chief points of which I proceed to quote:—

"(1) The first illusion to which Mrs. A. was subject, was one which affected only the ear. On the 21st of December, 1830, about half-past four in the afternoon, she was standing near the fire in the hall, and on the point of going up to dress, when she heard, as she supposed, her husband's voice calling her by name. '——, ——, come here! come to me!' She imagined that he was calling at the door to have it opened; but upon going there and opening the door, she was surprised to find no person there. Upon returning to the fire she again heard the same voice calling out very distinctly and loudly, '——, come, come here!' She then opened two other doors of the same room, and, upon seeing no person, she returned to the fire-place. After a few moments she heard the same voice still calling, 'Come to me, come! come away!' in a loud, plaintive, and somewhat impatient tone; she answered as loudly, 'Where are you? I don't know where you are,' still imagining that he was somewhere in search of her; but receiving no answer, she shortly went upstairs. On Mr. A.'s return to the house, about half an hour afterwards, she inquired why he had called to her so often, and where he was, and she was of course greatly surprised to learn that he had not been near the house at the time. A similar illusion, which excited no particular notice at the time, occurred to Mrs. A. when residing at Florence, about ten years before, and when she was in perfect health. When she was undressing after a ball, she heard a voice call her repeatedly by name, and she was at that time unable to account for it.

"(2) The next illusion which occurred to Mrs. A. was of a more alarming character. On the 30th of December, about four o'clock in the afternoon, Mrs. A. came down stairs into the drawing-room, which she had quitted only a few minutes before, and, on entering the room, she saw her husband, as she supposed, standing with his back to the fire. As he had gone out to take a walk about half an hour before, she was surprised to see him there, and asked him why he had returned so soon. The figure looked fixedly at her with a serious and thoughtful expression of countenance, but did not speak. Supposing that his mind was absorbed in thought, she sat down in an arm-chair near the fire, and within two feet, at most, of the figure, which she still saw standing before her. As its eyes, however, still continued to be fixed upon her, she said, after the lapse of a few minutes, 'Why don't you speak?' The figure immediately moved off towards the window at the further end of the room, with its eyes still gazing on her, and it passed so very close to her in doing so, that she was struck by the circumstance of hearing no step or sound, nor feeling her clothes brushed against, nor even any agitation in the air.

"Although she was now convinced that the figure was not her husband, yet she never for a moment supposed that it was anything supernatural, and was soon convinced that it was a spectral illusion. As soon as this conviction had established itself in her mind, she recollected the experiment which I had suggested of trying to double the object; but before she was able distinctly to do this, the figure had retreated to the window, where it disappeared. Mrs. A. immediately followed it, shook the curtains, and examined the window, the impression having been so distinct and forcible, that she was unwilling to believe that it was not a reality. Finding, however, that the figure had no natural means of escape, she was convinced that she had seen a spectral apparition like that recorded in Dr. Hibbert's work, and she consequently felt no alarm or agitation. The appearance was seen in bright daylight, and lasted four or five minutes. When the figure stood close to her, it concealed the real objects behind it, and the apparition was fully as vivid as the reality.

"(3) On these two occasions Mrs. A. was alone, but when the next phantom appeared, her husband was present. This took place on the 4th of January, 1830. About ten o'clock at night, when Mr. and Mrs. A. were sitting in the drawing-room, Mr. A. took up the poker to stir the fire, and when he was in the act of doing this, Mrs. A. exclaimed, 'Why, there's the cat in the room!' 'Where?' exclaimed Mr. A. 'There, close to you,' she replied. 'Where?' he repeated. 'Why, on the rug, to be sure, between yourself and the coal-scuttle.' Mr. A. who had still the poker in his hand, pushed it in the direction mentioned. 'Take care,' cried Mrs. A. 'take care! you are hitting her with the poker.' Mr. A. again asked her to point out exactly where she saw the cat. She replied, 'Why, sitting up there close to your feet on the rug; she is looking at me. It is Kitty—come here, Kitty!' There were two cats in the house, one of which went by this name, and they were rarely, if ever, in the drawing-room.

"At this time Mrs. A. had no idea that the sight of the cat was an illusion. When she was asked to touch it, she got up for the purpose, and seemed as if she were pursuing something which moved away. She followed a few steps, and then said, 'It has gone under the chair.' Mr. A. assured her that it was an illusion, but she would not believe it. He then lifted up the chair, and Mrs. A. saw nothing more of it. The room was searched all over, and nothing found in it. There was a dog lying on the hearth, who would have betrayed great uneasiness if a cat had been in the room, but he lay perfectly quiet. In order to be quite certain, Mr. A. rang the bell, and sent for the cats, both of which were found in the housekeeper's room.

"(4) About a month after this occurrence, Mrs. A. who had taken a somewhat fatiguing drive during the day, was preparing to go to bed about eleven o'clock at night, and, sitting before the dressing-glass, was occupied in arranging her hair. She was in a listless and drowsy state of mind, but fully awake. When her fingers were in active motion among the papillotes, she was suddenly startled by seeing in the mirror the figure of a near relative, who was then in Scotland, and in perfect health. The apparition appeared over her left shoulder, and its eyes met hers in the glass. It was enveloped in grave-clothes, closely pinned, as is usual with corpses, round the head and under the chin; and, though the eyes were open, the features were solemn and rigid. The dress was evidently a shroud, as Mrs. A. remarked even the punctured pattern usually worked in a peculiar manner round the edges of that garment. Mrs. A. described herself as, at the time, sensible of a feeling like what we conceive of fascination, compelling her, for a time, to gaze upon this melancholy apparition, which was as distinct and vivid as any reflected reality could be, the light of the candle upon the dressing-table appearing to shine fully upon its face. After a few minutes she turned round to look for the reality of the form over her shoulder, but it was not visible, and it had also disappeared from the glass when she looked again in that direction.

* * * * * *

"(7) On the 17th March, Mrs. A. was preparing for bed. She had dismissed her maid, and was sitting with her feet in hot water. Having an excellent memory, she had been thinking upon and repeating to herself a striking passage in the *Edinburgh Review*, when, on raising her eyes, she saw seated in a large easy-chair before her the figure of a deceased friend, the sister of Mr. A. The figure was dressed, as had been usual with her, with great neatness, but in a gown of a peculiar kind, such as Mrs. A. had never seen her wear, but exactly such as had been described to her by a common friend as having been worn by Mr. A.'s sister during her last visit to England. Mrs. A. paid particular attention to the dress, air, and appearance of the figure, which sat in an easy attitude in the chair, holding a handkerchief in one hand. Mrs. A. tried to speak to it, but experienced a difficulty in doing so, and in about three minutes the figure disappeared.

"About a minute afterwards, Mr. A. came into the room, and found Mrs. A. slightly nervous, but fully aware of the delusive nature of the apparition. She described it as having all the vivid colouring and apparent reality of life; and, for some hours preceding this and other visions, she experienced a peculiar sensation in her eyes, which seemed to be relieved when the vision had ceased.

* * * * * *

"(9) On the 11th October, when sitting in the drawing-room, on one side of the fire-place, she saw the figure of another deceased friend moving towards her from the window at the farther end of the room. It approached the fire-place, and sat down in the chair opposite. As there were several persons in the room at the time, she describes the idea uppermost in her mind to have been a fear lest they should be alarmed at her staring, in the way she was conscious of doing, at vacancy, and should fancy her intellect disordered. Under the influence of this fear, and recollecting a story of a similar effect in your* work on Demonology, which she had lately read, she summoned up the requisite resolution to enable her to cross the space before the fire-place, and seat herself in the same chair with the figure. The apparition remained perfectly distinct till she sat down, as it were, in its lap, when it vanished."

It should be mentioned that Mrs. A. was naturally a person of very vivid imagination, and that, at the time the most notable of these illusions appeared, her health was weak from bronchitis and enfeebled digestion.

It is obvious that nothing but the singular courage and clear intellect of Mrs. A. prevented her from becoming a mine of ghost stories of the most excellently authenticated kind. And the particular

* Sir Walter Scott; to whom Sir David Brewster's letters on natural magic were addressed.

value of her history lies in its showing, that the clearest testimony of the most unimpeachable witness may be quite inconclusive as to the objective reality of something which the witness has seen.

Mrs. A. undoubtedly saw what she said she saw. The evidence of her eyes as to the existence of the apparitions, and of her ears to those of the voices, was, in itself, as perfectly trustworthy as their evidence would have been had the objects really existed. For there can be no doubt that exactly those parts of her retina which would have been affected by the image of a cat, and those parts of her auditory organ which would have been set vibrating by her husband's voice, or the portions of the sensorium with which these organs of sense are connected, were thrown into a corresponding state of activity by some internal cause.

What the senses testify is neither more nor less than the fact of their own affection. As to the cause of that affection they really say nothing, but leave the mind to form its own judgment on the matter. A hasty or superstitious person in Mrs. A.'s place would have formed a wrong judgment, and would have stood by it on the plea that "she must believe her senses."

8. The delusions of the judgment, produced not by abnormal conditions of the body, but by unusual or artificial combinations of sensations, or by suggestions of ideas, are exceedingly numerous, and, occasionally, are not a little remarkable.

Some of those which arise out of the sensation of touch have already been noted. I do not know of any produced through smell or taste, but hearing is a fertile source of such errors.

What is called *Ventriloquism* (speaking from the belly), and is not uncommonly ascribed to a mysterious power of producing voice somewhere else than in the larynx, depends entirely upon the accuracy with which the performer can simulate sounds of a particular character, and upon the skill with which he can suggest a belief in the existence of the causes of these sounds. Thus, if the ventriloquist desire to create the belief that a voice issues from the bowels of the earth, he imitates with great accuracy the tones of such a half-stifled voice, and suggests the existence of some one uttering it by directing his answers and gestures towards the ground. These gestures and tones are such as would be produced by a given cause; and no other cause being apparent, the mind of the bystander insensibly judges the suggested cause to exist.

9. The delusions of the judgment through the sense of sight, *optical delusions*, as they are called, are more numerous than any others, because such a great number of what we think to be simple visual sensations are really very complex aggregates of visual sensations, tactile sensations, judgments, and recollections of former sensations and judgments.

It will be instructive to analyse some of these judgments into their principles, and to explain the delusions by the application of these principles.

10. *When an external body is felt by the touch to be in a given place, the image of that body falls on a point of the retina which lies at one end of a straight line joining the body and the retina, and traversing a particular region of the centre of the eye. This straight line is called the* OPTIC AXIS.

Conversely, when any part of the surface of *the retina is excited, the luminous sensation is referred by the mind to some point outside the body, in the direction of the optic axis.*

It is for this reason that when a phosphene is created by pressure, say on the outer and lower side of the eyeball, the luminous image appears to lie above, and to the inner side of, the eye. Any external object which could produce the sense of light in the part of the retina pressed upon, must, in fact, occupy this position; and hence the mind refers the light seen to an object in that position.

11. The same kind of explanation is applicable to the apparent paradox that, while all the pictures of external objects are certainly inverted on the retina by the refracting media of the eye, we nevertheless see them upright. It is difficult to understand this, until one reflects that the retina has, in itself, no means of indicating to the mind which of its parts lies at the top, and which at the bottom; and that the mind learns to call an impression on the retina high or low, right or left, simply on account of the association of such an impression with certain coincident tactile impressions. In other words, when one part of the retina is affected, the object causing the affection is found to be near the right hand; when another, the left; when another, the hand has to be raised to reach the object; when yet another, it has to be depressed to reach it. And thus the several impressions on the retina are called right, left, upper, lower, quite irrespectively of their real positions, of which the mind has, and can have, no cognizance.

12. *When an external body is ascertained by touch to be single, it forms but one image on the retina of a single eye; and when two or more*

images fall on the retina of a single eye, they ordinarily proceed from a corresponding number of bodies which are distinct to the touch.

Conversely, the sensation of two or more images is judged by the mind to proceed from two or more objects.

If two pin-holes be made in a piece of cardboard at a distance less than the diameter of the pupil, and a small object like the head of a pin be held pretty close to the eye, and viewed through these holes, two images of the head of the pin will be seen. The reason of this is, that the rays of light from the head of the pin are split by the card into two minute pencils, which pass into the eye on either side of its centre, and cannot be brought to one focus on account of the nearness of the pin to the eye. Hence they fall on different parts of the retina, and each pencil, being very small, makes a tolerably distinct image of its own on the retina. Each of these images is now referred outward (§ 10) in the direction of the appropriate optic axis, and two pins are apparently seen instead of one. A like explanation applies to *multiplying glasses* and *doubly refracting* crystals, both of which, in their own ways, split the pencils of light proceeding from a single object into two or more separate bundles. These give rise to as many images, each of which is referred by the mind to a distinct external object.

13. *Certain visual phenomena ordinarily accompany those-products of tactile sensation to which we give the name of size, distance, and form. Thus, other things being alike, the space of the retina covered by the image of a large object is larger than that covered by a small object; while that covered*

by a near object is larger than that covered by a distant object; and, other conditions being alike, a near object is more brilliant than a distant one. Furthermore, the shadows of objects differ with the forms of their surfaces, as determined by touch.

Conversely, if these visual phenomena can be produced, they inevitably suggest a belief in the existence of objects competent to produce the corresponding tactile sensations.

What is called *perspective,* whether *solid* or *aërial,* in drawing, or painting, depends on the application of these principles. It is a kind of visual ventriloquism—the painter putting upon his canvas all the conditions requisite for the production of images on the retina, having the form, relative size, and intensity of colour of those which would actually be produced by the objects themselves in nature. And the success of his picture, as an imitation, depends upon the closeness of the resemblance between the images it produces on the retina, and those which would be produced by the objects represented.

14. To most persons the image of a pin, at five or six inches from the eye, appears blurred and indistinct—the eye not being capable of adjustment to so short a focus. If a small hole be made in a piece of card, the circumferential rays which cause the blur are cut off, and the image becomes distinct. But at the same time it is magnified, or looks bigger, because the image of the pin occupies a much larger extent of the retina when close than when distant. All convex glasses produce the same effect—while concave lenses diminish the apparent size of an object, because they diminish the size of its image on the retina.

15. The moon, or the sun, when near the horizon appear very much larger than they are when high in the sky. When in the latter position, in fact, we have nothing to compare them with, and the small extent of the retina which their images occupy suggests small absolute size. But as they set, we see them passing behind great trees and buildings which we know to be very large and very distant, and yet occupying a larger space on the retina than the latter do. Hence the vague suggestion of their larger size.

16. If a convex surface be lighted from one side, the side towards the light is bright—that turned from the light, dark, or in shadow; while a concavity is shaded on the side towards the light, bright on the opposite side.

If a new half-crown, or a medal with a well-raised head upon its face, be lighted sideways by a candle, we at once know the head to be raised (or a *cameo*) by the disposition of the light and shade; and if an *intaglio*, or medal on which the head is hollowed out, be lighted in the same way, its nature is as readily judged by the eye.

But now, if either of the objects thus lighted be viewed with a convex lens, which inverts its position, the light and dark sides will be reversed. With the reversal the judgment of the mind will change, so that the cameo will be regarded as an intaglio, and the intaglio as a cameo; for the light still comes from where it did, but the cameo appears to have the shadows of an intaglio, and *vice versâ.* So completely, however, is this interpretation of the facts as a matter of judgment, that if a pin be stuck beside the medal so as to throw a shadow, the pin and its shadow, being reversed by the lens, will suggest that the direction of the light is also reversed, and the medals will seem to be what they really are.

17. *Whenever an external object is watched rapidly changing its form, a continuous series of different pictures of the object is impressed upon the same spot of the retina.*

Conversely, if a continuous series of different pictures of one object is impressed upon one part of the retina, the mind judges that they are due to a single external object, undergoing changes of form.

This is the principle of the curious toy called the *thaumatrope*, by the help of which, on looking through a hole, one sees images of jugglers throwing up and catching balls, or boys playing at leap-frog over one another's backs. This is managed by painting at intervals, on a disk of card, figures and jugglers in the attitudes of throwing, waiting to catch, and catching; or boys "giving a back," leaping, and coming into position after leaping. The disk is then made to rotate before an opening, so that each image shall be presented for an instant, and follow its predecessor before the impression of the latter has died away. The result is that the succession of different pictures irresistibly suggests one or more objects undergoing successive changes—the juggler seems to throw the balls, and the boys appear to jump over one another's backs.

18. *When an external object is ascertained by touch to be single, the centres of its retinal images in the two eyes fall upon the centres of the yellow spots of the two eyes, when both eyes are directed towards it; but if there be two external objects, the centres*

of both their images cannot fall, at the same time, upon the centres of the yellow spots.

Conversely, when the centres of two images, formed simultaneously in the two eyes, fall upon the centres of the yellow spots, the mind judges the images to be caused by a single external object; but if not, by two.

This seems to be the only admissible explanation of the facts, that an object which appears single to the touch and when viewed with one eye, also appears single when it is viewed with both eyes, though two images of it are necessarily formed; and on the other hand, that when the centres of the two images of one object do not fall on the centres of the yellow spots, both images are seen separately, and we have double vision. In squinting, the axes of the two eyes do not converge equally towards the object viewed. In consequence of this, when the centre of the image formed by one eye falls on the yellow spot, the corresponding part of that formed by the other eye does not, and double vision is the result.

19. *In single vision with two eyes, the axes of the two eyes, of the movements of which the muscular sense gives an indication, cut one another at a greater angle when the object approaches, at a less angle when it goes further off.*

Conversely, if without changing the position of an object, the axes of the two eyes which view it can be made to converge or diverge, the object will seem to approach or go further off.

In the instrument called the *pseudoscope,* mirrors or prisms are disposed in such a manner that the rays of light from a stationary object can be caused to alter the angle at which they enter the two eyes, and so require the axes of these eyes to become more or less convergent. In the former case the object seems to approach; in the latter, to increase its distance.

20. *When a body of moderate size, ascertained by touch to be solid, is viewed with both eyes, the images of it, formed by the two eyes, are necessarily different (one showing more of its right side, the other of its left side). Nevertheless, they coalesce into a common image, which gives the impression of solidity.*

Conversely, if the two images of the right and left aspects of a solid body be made to fall upon the retinæ of the two eyes in such a way as to coalesce into a common image, they are judged by the mind to proceed from the single solid body which alone, under ordinary circumstances, is competent to produce them.

The *stereoscope* is constructed upon this principle. Whatever its form, it is so contrived as to throw the images of two pictures of a solid body, such as would be obtained by the right and left eye of a spectator, on to such parts of the retinæ of the person who uses the stereoscope as would receive these images, if they really proceeded from one solid body. The mind immediately judges them to arise from a single external solid body, and sees such a solid body in place of the two pictures.

The operation of the mind upon the sensations presented to it by the two eyes is exactly comparable to that which takes place when, on holding a marble between the finger and thumb, we at once declare it to be a single sphere (§ 4). That which is absolutely presented to the mind by the sense of touch in this case is by no means the sensation of one spheroidal body, but two distinct sensations of two convex surfaces. That these two distinct convexities belong to one sphere, is an act of judgment, or process of unconscious reasoning, based upon many particulars of past and present experience, of which we have, at the moment, no distinct consciousness.

LESSON XI.

THE NERVOUS SYSTEM AND INNERVATION.

1. THE sensory organs are, as we have seen, the channels through which particular physical agents are enabled to excite the sensory nerves with which these organs are connected; and the activity of these nerves is evidenced by that of the central organ of the nervous system, which becomes manifest as a state of consciousness—the sensation.

We have also seen that the muscles are instruments by which a motor nerve, excited by the central organ with which it is connected, is able to produce motion.

The sensory nerves, the motor nerves, and the central organ, constitute the greater part of the *nervous system*, which, with its function of *innervation*, we must now study somewhat more closely, and as a whole.

2. The nervous apparatus consists of two sets of nerves and nerve-centres, which are intimately connected together, and yet may be conveniently studied apart. These are the *cerebro-spinal* system and the *sympathetic* system. The former consists of the *cerebro-spinal axis* (composed of the *brain* and *spinal cord*) and the *cerebral* and *spinal nerves*, which are connected with this axis. The latter comprises the chain of *sympathetic ganglia*, the nerves which they give off, and the nervous cords

by which they are connected with one another and with the cerebro-spinal nerves.

3. The *cerebro-spinal axis* lies in the cavity of the skull and spinal column, the bony walls of which cavity are lined by a very tough fibrous membrane, serving as the periosteum of the component bones of this region, and called the *dura mater*. The brain and spinal cord themselves are closely invested by a very vascular fibrous tissue, called *pia mater*. The numerous blood-vessels supplying these organs run for some distance in the pia mater, and where they pass into the substance of the brain or cord, the fibrous tissue of the pia mater accompanies them to a greater or less depth.

The outer surface of the *pia mater*, and the inner surface of the *dura mater*, pass into a delicate fibrous tissue, lined by an epithelium, which is called the *arachnoid* membrane. Thus one layer of arachnoid coats the brain and spinal cord, and another lines the dura mater. As these layers become continuous with one another at various points, the arachnoid forms a sort of shut sac, like the *pericardium;* and, in common with other serous membranes, it secretes a fluid, the *arachnoid fluid*, into its interior. The interspace between the internal and external layers of the arachnoid of the brain is, for the most part, very small; that between the corresponding layers of the arachnoid of the spinal cord is larger.

4. The *spinal cord* (Fig. 70) is a column of greyish-white soft substance, extending from the top of the spinal canal, where it is continuous with the brain, to about the second lumbar vertebra, where it tapers off into a filament. A deep fissure, the *anterior fissure*, divides it in the middle line in front, nearly down to its centre; and a similar cleft, the

posterior fissure, also extends nearly to its centre in the middle line behind. The pia mater extends into each of these fissures, and supports the vessels which supply the cord with blood. In consequence of the presence of these fissures, only a narrow bridge of the substance of the cord connects its two halves, and this bridge is traversed throughout its entire length by a minute canal, the *central canal* of the cord.

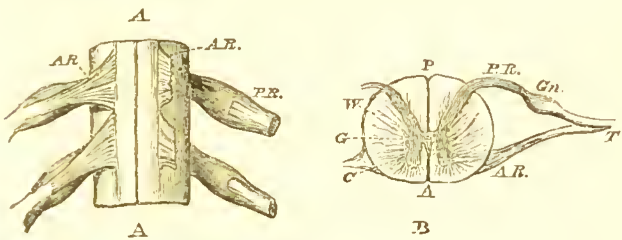

FIG. 70.

The Spinal Cord.—A. A front view of a portion of the cord. On the right side, the anterior roots, *A.R.*, are entire; on the left side they are cut, to show the posterior roots, *P.R.* B. A transverse section of the cord. *A*, the anterior fissure; *P*, the posterior fissure; *G*, the central canal; *C*, the grey matter; *W*, the white matter; *A.R.* the anterior root, *P.R.* the posterior root, *Gn.* the ganglion, and *T*, the trunk, of a spinal nerve.

Each half of the cord is divided longitudinally into three equal parts, by the lines of attachment of two parallel series of delicate bundles of nervous filaments, the *roots of the spinal nerves.* The roots of the nerves which arise along that line which is nearer the posterior surface of the cord are called *posterior roots;* those which arise along the other line are the *anterior roots.* A certain number of anterior and posterior roots, on the same level on each side of the cord, converge and form anterior and posterior bundles, and then the two bundles, anterior and posterior, coalesce into the *trunk of a spinal nerve;* but, before doing so, the posterior bundle presents an enlargement—the *ganglion of the posterior root.*

The trunks of the spinal nerves pass out of the spinal canal by apertures between the vertebræ, called the *intervertebral foramina*, and then divide and subdivide, their ultimate ramifications going to the muscles and to the skin.

There are thirty-one pairs of these spinal nerves, and, consequently, twice as many sets of roots of spinal nerves given off, in two lateral series, from each half of the cord.

5. A transverse section of the cord (Fig. 70, B) shows that each half contains two substances—a *white substance* on the outside, and a *greyish-red substance* in the interior. And this grey substance is so disposed that, in a transverse section, it looks something like a crescent, with one end bigger than the other, and with the concave side turned outwards. The two ends of the crescent are called its *horns* or *cornua*, the one directed forwards being the *anterior cornu;* the one turned backwards the *posterior cornu.* The convex sides of the cornua of the grey matter approach one another, and are joined by the bridge which contains the central canal.

Many of the nerve-fibres of which the anterior roots are composed may be traced into the anterior cornu, while those of the posterior roots enter the posterior cornu.

6. The physiological properties of the organs now described are very remarkable.

If the trunk of a spinal nerve be irritated in any way, as by pinching, cutting, galvanizing, or applying a hot body, two things happen: in the first place, all the muscles to which filaments of this nerve are distributed, contract; in the second, acute pain is felt, and the pain is referred to that part of the skin to which fibres of the nerve are distributed. In other words, the effect of irritating the trunk of a nerve is the same as that of irritating its component fibres at their terminations.

The effects just described will follow upon irritation of any part of the branches of the nerve: except that when a branch is irritated, the only muscles directly affected, and the only region of the skin to which pain is referred, will be those to which that branch sends nerve-fibres. And these effects will follow upon irritation of any part of the trunk of a nerve up to the point at which the anterior and posterior bundles of root fibres unite.

7. If the anterior bundle of root fibres be irritated in the same way, only half the previous effects are brought about. That is to say, all the muscles to which the nerve is distributed contract, but no pain is felt.

So again, if the posterior, ganglionated, bundle be irritated, only half the effect of irritating the whole trunk is produced. But it is the other half; that is to say, none of the muscles to which the nerve is distributed contract, but intense pain is referred to the whole area of skin to which the fibres of the nerve are distributed.

8. It is clear enough, from these experiments, that all the power of causing muscular contraction which a spinal nerve possesses, is lodged in the fibres which compose its anterior roots; and all the power of giving rise to sensation, in those of its posterior

roots. Hence the anterior roots are commonly called *motor*, and the posterior *sensory*.

The same truth may be illustrated in other ways. Thus, if, in a living animal, the anterior roots of a spinal nerve be cut, the animal loses all control over the muscles to which that nerve is distributed, though the sensibility of the region of the skin supplied by the nerve is perfect. If the posterior roots be cut, sensation is lost, and voluntary movement remains. But, if both roots be cut, neither voluntary movement or sensibility are any longer possessed by the part supplied by the nerve. The muscles are said to be *paralysed*, and the skin may be cut, or burnt, without any sensation being excited.

If, when both roots are cut, that end of the motor root which remains connected with the trunk of the nerve be irritated, the muscles contract; while, if the other end be so treated, no apparent effect results. On the other hand, if the end of the sensory root connected with the trunk of the nerve be irritated, no apparent effect is produced, while, if the end connected with the cord be thus served, violent pain immediately follows.

When no apparent effect follows upon the irritation of any nerve, it is not probable that the molecules of the nerve remain unchanged. On the contrary, it would appear that the same change occurs in all cases; but a motor nerve is connected with nothing that can make that change apparent save a muscle: and a sensory nerve with nothing that can show an effect but the central nervous system.

9. It will be observed that in all the experiments mentioned there is evidence that, when a nerve is irritated, a something, probably a change in the arrangement of its molecules, is propagated along

the nerve-fibres. If a motor or a sensory nerve be irritated, at any point, contraction in the muscle, or sensation in the central organ, immediately follows. But if the nerve be cut, or even tightly tied at any point between the part irritated and the muscle or central organ, the effect at once ceases, just as cutting a telegraph wire stops the transmission of the electric current or impulse. When a limb, as we say, "goes to sleep," it is because the nerves supplying it have been subjected to pressure sufficient to destroy the nervous* continuity of the fibres. We lose voluntary control over, and sensation in, the limb, and these powers are only gradually restored as that nervous continuity returns.

Having arrived at this notion of an impulse travelling along a nerve, we readily pass to the conception of a sensory nerve as a nerve which, when active, brings an impulse to the central organ, or is *afferent;* and of a motor nerve, as a nerve which carries away an impulse from the organ, or is *efferent.* It is very convenient to use these terms to denote the two great classes of nerves; for, as we shall find (§ 12), there are afferent nerves which are not sensory, while there may be in man, and certainly are in animals, efferent nerves which are not motor, in the sense of inducing muscular contraction.

* Their "nervous continuity"—because their physical continuity is not interrupted as a whole, but only that of the substance which acts as a conductor of the nervous influence; or, it may be that only the conducting power of a part of that substance is interfered with. Imagine a telegraph cable, made of delicate caoutchouc tubes, filled with mercury—a squeeze would interrupt the "electrical continuity" of the cable, without destroying its physical continuity. This analogy may not be exact, but it helps to make the nervous phenomena intelligible.

Such, for example, are the nerves by which the electrical fishes give rise to discharges of electricity from peculiar organs to which those nerves are distributed.

10. There is no difference in structure, in chemical or in physical character, between afferent and efferent nerves. The impulse which travels along them requires a certain time for its propagation, and is vastly slower than many other forces—even slower than sound.

It is found that, during life, the trunk of a nerve is in a state of electrical activity, the ends of any segment being in a different polar condition to its surface. Hence, if one pole of a galvanometer be connected with the cut end of a nerve, and the other with its surface, a current passes, and the needle is deflected to a certain extent—say 20 degrees. If, under these circumstances, the nerve be irritated (the result of which, of course, is the propagation of an impulse along its molecules), the deviation of the needle at once diminishes, falling, say, to 15 degrees.

This is called *negative deflection*, and the importance of the experiment consists in the demonstration which it affords of the existence of a close relation between the force proper to nervous matter and one of the ordinary forces of nature, electricity—though this close relation must by no means be mistaken for identity.

11. Up to this point our experiments have been confined to the nerves. We may now test the properties of the spinal cord in a similar way. If the cord be cut across (say in the middle of the back), the legs, and all the parts supplied by nerves which come off below the section, will be insensible, and

no effort of the will can make them move; while all the parts above the section will retain their ordinary powers.

When a man hurts his back by an accident, the cord is not unfrequently so damaged as to be virtually cut in two, and then paralysis and insensibility of the lower part of the body ensue.

If, when the cord is cut across in an animal, the cut end of the portion below the division, or away from the brain, be irritated, violent movements of all the muscles supplied by nerves given off from the lower part of the cord take place, but there is no sensation. On the other hand, if the posterior root of any nerve attached to the part of the cord, which is still connected with the brain, be irritated, great pain ensues, but there is no movement of the muscles of the part below the cut.

12. Thus it may be said that, in relation to the brain, the cord is a great mixed motor and sensory nerve. But it is also much more. For if the trunk of a spinal nerve be cut through, so as to sever its connexion with the cord, an irritation of the skin to which the sensory fibres of that nerve are distributed, produces neither motor nor sensory effect.

But if the cord be cut through, so as to sever its connexion with the brain, irritation applied to the skin of the parts below the section, though it gives rise to no sensation, may produce violent motion of the parts supplied with motor nerves from the segment of the cord below the section.

Thus, in the case supposed above, of a man whose legs are paralysed and insensible from spinal injury, tickling the soles of the feet will cause the legs to kick out convulsively. And, as a broad fact, it may be said that, so long as both roots of the spinal nerves remain connected with the cord, irritation of any afferent nerve is competent to give rise to excitement of some, or the whole, of the efferent nerves so connected.

If the cord be cut across a second time at any distance below the first section, the efferent nerves below the second cut will no longer be affected by irritation of the afferent nerves above it—but only of those below the second section. Or, in other words, in order that an afferent impulse may be converted into an efferent one by the spinal cord, the afferent nerve must be in uninterrupted material communication with the efferent nerve, by means of the substance of the spinal cord.

This peculiar power of the cord, by which it is competent to convert afferent into efferent impulses, is that which distinguishes it physiologically, as a central organ, from a nerve, and is called *reflex action.* It is a power possessed by the grey matter, and not by the white substance of the cord.

13. The number of the efferent nerves which may be excited by the reflex action of the cord, is not regulated by the number of the afferent nerves which are stimulated by the irritation which gives rise to the reflex action. Nor does a simple excitation of the afferent nerve by any means imply a corresponding simplicity in the arrangement and succession of the reflected motor impulses. Tickling the sole of the foot is a very simple excitation of the afferent fibres of its nerves; but, in order to produce the muscular actions by which the legs are drawn up, a great multitude of efferent fibres must act in regulated combination. In fact, in a multitude of cases, a reflex action is to be regarded

rather as an order given by an afferent nerve to the cord, and executed by it, than as a mere rebound of the afferent impulse into the first efferent channels open to it.

14. Thus the spinal cord is, in part, merely a transmitter of impressions to and from the brain; but, in part, it is an independent nervous centre, capable of originating combined movements upon the reception of the impulse of an afferent nerve.

Regarding it as a conductor, the question arises, Do all parts of it conduct all kinds of impressions indifferently? Or are certain kinds of impressions communicated only through particular parts of the cord?

The following experiments furnish a partial reply to these questions:—

If the anterior half of the white matter of the dorsal part of the cord be cut through, the will is no longer capable of exerting any influence on the muscles which are supplied with nerves from the lower segment of the cord. A similar section, carried through the posterior half of the white matter in this region, has no effect on the transmission of voluntary impulses. It is obvious, therefore, that, in the dorsal part of the cord, nervous impulses from the brain are sent through the anterior part of the white matter.

The posterior half of the white matter may be cut through at one point, and the anterior half at a point a little higher up, so that all the white fibres shall be divided transversely by the one cut or the other, without any interference with the material continuity of the cord, or damage to the grey matter.

When this has been done, irritation of those sensory nerves which are connected with parts below the section excites the sensation of pain as strongly as ever. Hence it follows, that the afferent impulses, which excite pain when they reach the brain, pass through, and are conveyed by, the grey matter. And it has been found, by experiment, that, so long as even a small portion of the grey matter remains entire, these afferent impulses are efficiently transmitted. Singularly enough, however, irritation of the grey matter itself does not cause pain.

If one half of the cord, say the right, be cut through, transversely, down to its very middle, so as to interrupt all continuity of both white and grey matter between its upper and lower parts, irritation of the skin of the right side of the body, below the line of section, will give rise to as much pain as before, but all voluntary power will be lost in those muscles of that side, which are supplied by nerves coming off from the lower portion of the cord. Hence it follows, that the channels by which the afferent impulses are conveyed must cross over from the side of the cord which they enter to the opposite side; while the efferent impulses, sent down from the brain, must travel along that side of the cord by which they pass out.

If this be true, it is clear that a longitudinal section, taken through the exact middle of the cord, will greatly impair, if not destroy, the sensibility of both sides of the body below the section, but will leave the muscles perfectly under the control of the will. And it is found experimentally that such is the case.

15. Such are the functions of the spinal cord, taken as a whole. But particular regions of this

organ appear to be charged with the special function of acting as centres for those *vaso-motor* nerves,

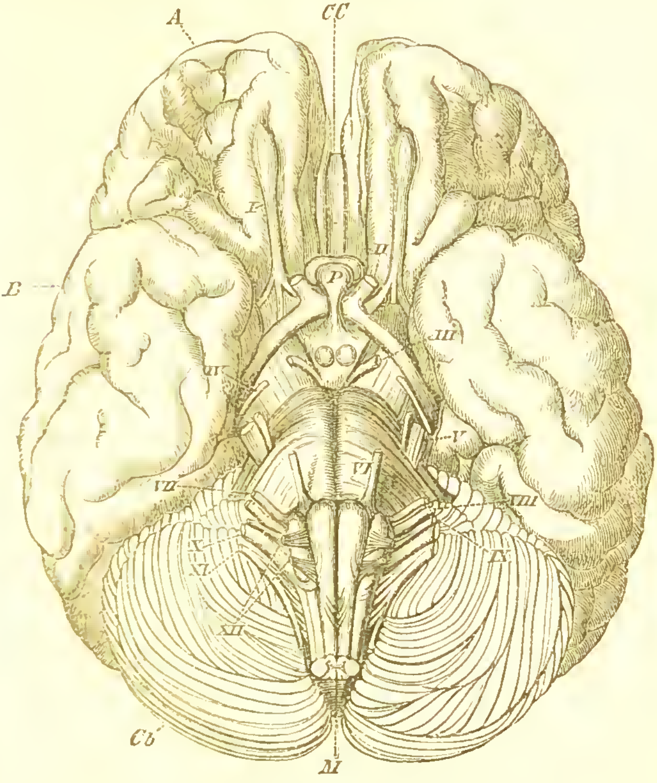

FIG. 71.

The base of the brain.—*A.* frontal lobe, *B.* temporal lobe of the cerebral hemispheres; *C.C.* corpus callosum; *Cb.* cerebellum; *M.* medulla oblongata; *P.* the pituitary body; *I.* the olfactory nerve; *II.* the optic nerve; *III. IV. VI.* the nerves of the muscles of the eye; *V.* the trigeminal nerve; *VII.* the portio dura; *VIII.* the auditory nerve; *IX.* the glossopharyngeal; *X.* the pneumogastric; *XI.* the spinal accessory; *XII.* the hypoglossal, or motor nerve of the tongue. The number *VI.* is placed upon the *Pons Varolii.* The *crura cerebri* are the broad bundles of fibres which lie between the third and the fourth nerves on each side.

which supply the muscles of the vessels and of many of the viscera.

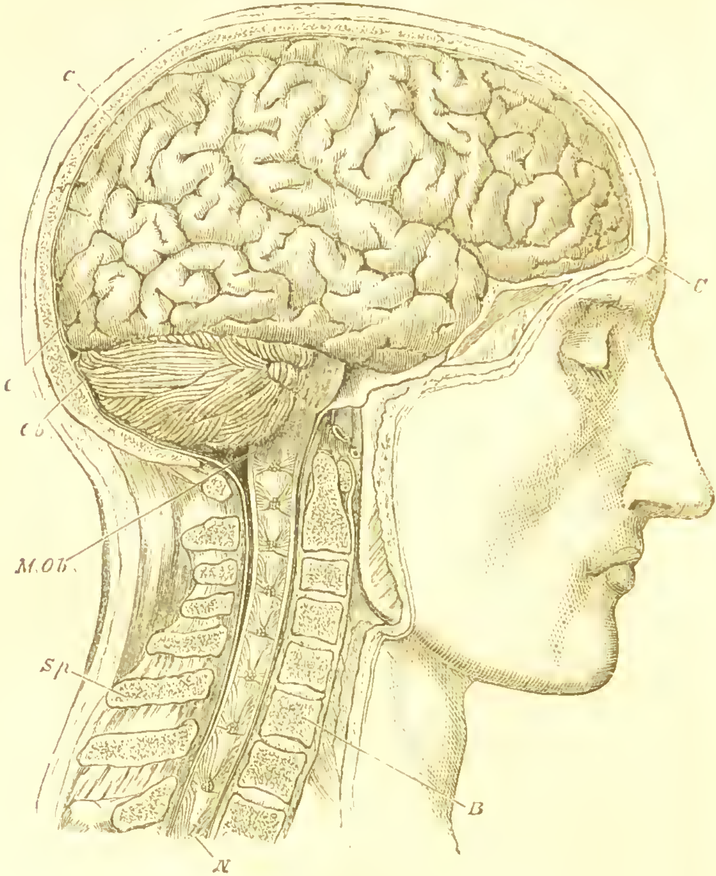

FIG. 72.

A side view of the brain and upper part of the spinal cord in place—the parts which cover the cerebro-spinal centres being removed; *CC.* the convoluted surface of the right cerebral hemisphere; *Cb.* the cerebellum; *M. Ob* the medulla oblongata; *B.* the bodies of the cervical vertebræ; *Sp.* their spines; *N.* the spinal cord with the spinal nerves.

For example, the muscular walls of the blood-vessels supplying the ear and the skin of the head generally, are made to contract, as has been already mentioned, by nervous fibres derived, immediately, from the sympathetic. These fibres, however, do not arise from the sympathetic ganglia, but simply pass through them on their way from the spinal cord, to the upper dorsal region of which they can all be traced. At least, this is the only conclusion to be drawn from the facts, that irritation of this region of the cord produces the same effect as irritation of the vaso-motor nerves themselves, and that destruction of this part of the cord paralyses them.

The grey matter of the upper part of the cord is therefore a *vaso-motor centre* for the head and face.

16. The brain (Fig. 71) is a complex organ, consisting of several parts, the hindermost of which, termed *medulla oblongata*, passes insensibly into, and, in its lower part, has the same structure as, the spinal cord.

Above, however, it widens out, and the central canal, spreading with it, becomes a broad cavity, which (leaving certain anatomical minutiæ aside) may be said to be widely open above. This cavity is termed the *fourth ventricle.* Overhanging the fourth ventricle is a great laminated mass, the *cerebellum* (*Cb.* Figs. 71, 72, 73). On each side, this organ sends down several layers of transverse fibres, which sweep across the brain and meet in the middle line of its base, forming a kind of bridge (called *Pons Varolii*, Fig. 71) in front of the medulla oblongata. The longitudinal nerve-fibres of the medulla oblongata pass forwards, among, and between these layers of transverse fibres; and become visible, in front of the pons, as two broad diverging bundles, called *crura cerebri* (Fig. 71). Above the crura cerebri lies a mass of nervous matter raised up into four hemispherical elevations, called *corpora quadrigemina* (C.Q. Fig. 73). Between these and the crura cerebri is a narrow passage, which leads from the fourth ventricle into what is termed the *third ventricle* of the brain. The third ventricle is a narrow cavity lodged between two great masses of nervous matter, called *optic thalami*, into which the crura cerebri pass. The roof of the third ventricle is merely membranous; and a peculiar body of unknown function, the *pineal gland*, is connected with it. The floor of the third ventricle is produced into a sort of funnel, which ends in another anomalous organ, the *pituitary body* (Pt. Fig. 73).

The third ventricle is closed, in front, by a thin layer of nervous matter; but, beyond this, on each side, there is an aperture in the boundary wall of the third ventricle which leads into a large cavity. The latter occupies the centre of the *cerebral hemisphere*, and is called the *lateral ventricle*. Each hemisphere is enlarged backwards, downwards, and forwards, into as many *lobes;* and the lateral ventricle presents corresponding prolongations, or *cornua*.

The floor of the lateral ventricle is formed by a mass of nervous matter, called the *corpus striatum*, into which the fibres that have traversed the optic thalamus enter (Fig. 73, *C.S.*).

The hemispheres are so large that they overlap all the other parts of the brain. and, in the upper view, hide them. Their applied faces are separated by a median fissure for the greater part of their extent; but, inferiorly, are joined by a thick mass of transverse fibres, the *corpus callosum* (Fig. 71, *C.C.*).

The outer surfaces of the hemispheres are marked out into *convolutions*, or *gyri*, by numerous deep *fissures* (or *sulci*), into which the pia mater enters. One large and deep fissure which separates the anterior from the middle division of the hemisphere is called the *fissure of Sylvius* (Fig. 72).

17. In the *medulla oblongata* the arrangement of the white and grey matter is substantially similar to that which obtains in the spinal cord; that is to say, the white matter is external, and the grey internal. But, in the *cerebellum* and *cerebral hemispheres*, the grey matter is external and the white internal; while, in the optic *thalami* and *corpora striata*, grey matter and white matter are variously intermixed.

18. Nerves are given off from the brain in pairs, which succeed one another from before backwards, to the number of twelve (Fig. 73).

The *first pair*, counting from before backwards, are the *olfactory nerves*, and the *second* are the *optic* nerves. The functions of these have already been described.

The *third pair* are called *motores oculi* (movers of the eye), because they are distributed to all the muscles of the eye except two.

The nerves of the *fourth pair* and of the *sixth pair* supply, each, one of the muscles of the eye, on each side; the fourth going to the superior oblique muscle, and the sixth to the external rectus. Thus the muscles of the eye, small and close together as they are, receive their nervous stimulus by three distinct nerves.

Each nerve of the *fifth pair* is very large. It has two roots, a motor and a sensory, and further

FIG. 73.

A diagram illustrating the arrangement of the parts of the brain and the origin of the nerves.—*H.* the cerebral hemispheres; *C.S.* corpus striatum; *Th.* optic thalamus; *P.* pineal gland; *Pt.* pituitary body; *C.Q.* corpora quadrigemina; *Cb.* cerebellum; *M.* medulla oblongata; *I.—XII.* the pairs of cerebral nerves; *Sp.* 1, *Sp.* 2, the first and second pairs of spinal nerves.

resembles a spinal nerve in having a ganglion on its sensory root. It is the nerve which supplies the skin of the face and the muscles of the jaws, and, having three chief divisions, is often called *trigeminal.*

The *seventh pair* furnish with motor nerves the muscles of the face, and some other muscles, and are called *facial.*

The *eighth pair* are the *auditory* nerves. As the seventh and eighth pairs of nerves leave the cavity of the skull together, they are often, and especially by English writers on anatomy, reckoned as one, divided into *portio dura*, or hard-part (the facial); and *portio mollis*, or soft part (the auditory) of the "seventh" pair.

The *ninth pair* in order, the *glossopharyngeal*, are mixed nerves; each being, partly, a nerve of taste, and, partly, a motor nerve for the pharyngeal muscles.

The *tenth pair* is formed by the two *pneumogastric* nerves. These very important nerves, and the next pair, are the only cerebral nerves which are distributed to regions of the body remote from the head. The pneumogastric supplies the larynx, the lungs, the liver, and the stomach, and branches of it are connected with the heart.

The *eleventh pair* again, called *spinal accessory*, differ widely from all the rest, in arising from the sides of the spinal marrow, between the anterior and posterior roots of the dorsal nerves. They run up, gathering fibres as they go, to the medulla oblongata, and then leave the skull by the same aperture as the pneumogastric and glossopharyngeal. They are purely motor nerves, while the pneumogastric is mainly sensory, or at least afferent. As, on each side, the glossopharyngeal, pneumogastric, and spinal accessory nerves leave the skull together, they are frequently reckoned as one pair, which is then counted as the *eighth*.

The last two nerves, by this method of counting, become the *ninth* pair, but they are, really, the *twelfth*. They are the motor nerves which supply the muscles of the tongue.

19. Of these nerves, the two foremost pair do

not properly deserve that name, but are really processes of the brain. The olfactory pair are prolongations of the cerebral hemispheres; the optic pair, of the walls of the third ventricle; and it is worthy of remark, that it is only these two pair of what may be called *false nerves* which arise from any part of the brain but the medulla oblongata—all the other *true nerves* being indirectly, or directly, traceable to that part of the brain, while the olfactory and optic nerves are not so traceable.

20. As might be expected from this circumstance alone, the medulla oblongata is an extremely important part of the cerebro-spinal axis, injury to it giving rise to immediate evil consequences of the most serious kind.

Simple puncture of one side of the floor of the fourth ventricle at once produces an increase of the quantity of sugar in the blood, beyond that which can be destroyed in the organism. The sugar passes off by the kidneys, and thus this slight injury to the medulla produces the disease called *diabetes*.

More extensive injury arrests the respiratory processes, the medulla oblongata being the nervous centre which gives rise to the contractions of the respiratory muscles, and keeps the respiratory pump at work.

If the injuries to the medulla oblongata be of such a kind as to irritate the roots of the pneumogastric nerve violently, death supervenes by the stoppage of the heart's action in the manner already described (see Lesson II.).

21. The afferent impulses, which are transmitted by the cord to the brain and awake sensation there, cross, as we have seen, from one half of the cord to

the other, immediately after they enter it by the posterior roots of the spinal nerves; while the efferent, or volitional, impulses from the brain remain, throughout the cord, in that half of it from which they will eventually pass by the anterior roots. But at the lower and front part of the medulla oblongata, these also cross over; and the white fibres which convey them are seen passing obliquely from left to right and from right to left in what is called the *decussation of the anterior pyramids* (Fig. 71). Hence, any injury, at a point higher up than the decussation, to the nerve-fibres which convey motor impulses from the brain, paralyses the muscles of the body and limbs of the opposite side.

Division, therefore, of one of the *crura cerebri*, say the right, gives rise to paralysis of the left side of the body and limbs, and the animal operated upon falls over to the left side, because the limbs of that side are no longer able to support the weight.

But as the motor nerves given off from the brain itself do not cross over in this way, it follows, that disease or injury at a given point, on one side of the medulla oblongata, involving at once the course of the volitional motor channels to the spinal marrow, and the origins of the cerebral motor nerves, will affect the same side of the head as that of the injury, but the opposite side of the body.

If the origin of the left facial nerve, for example, be injured, and the volitional motor fibres going to the cord destroyed, in the upper part of the medulla oblongata, the muscles of the face of the left side will be paralysed, and the features will be drawn over to the opposite side, the muscles of the right side having nothing to counteract their action. But it is the right arm, and the right leg and side of the body, which will be powerless.

22. The functions of most of the parts of the brain which lie in front of the medulla oblongata are, at present, very ill understood; but it is certain that extensive injury, or removal, of the cerebral hemispheres puts an end to intelligence and voluntary movement, and leaves the animal in the condition of a machine, working by the reflex action of the remainder of the cerebro-spinal axis.

Thus there can be no doubt that the cerebral hemispheres are the seat of powers, essential to the production of those phenomena which we term intelligence and will; but there is no satisfactory proof, at present, that the manifestation of any particular kind of mental faculty is especially allotted to, or connected with, the activity of any particular region of the cerebral hemispheres.

23. Even while the cerebral hemispheres are entire, and in full possession of their powers, the brain gives rise to actions which are as completely reflex as those of the spinal cord.

When the eyelids wink at a flash of light, or a threatened blow, a reflex action takes place, in which the afferent nerves are the optic, the efferent the facial. When a bad smell causes a grimace, there is a reflex action through the same motor nerve, while the olfactory nerves constitute the afferent channels. In these cases, therefore, reflex action must be effected through the brain, all the nerves involved being cerebral.

When the whole body starts at a loud noise, the afferent auditory nerve gives rise to an impulse which passes to the medulla oblongata, and thence affects the great majority of the motor nerves of the body.

24. It may be said that these are mere mechanical actions, and have nothing to do with the operations which we associate with intelligence. But let us consider what takes place in such an act as reading aloud. In this case, the whole attention of the mind is, or ought to be, bent upon the subject-matter of the book; while a multitude of most delicate muscular actions are going on, of which the reader is not in the slightest degree aware. Thus the book is held in the hand, at the right distance from the eyes; the eyes are moved from side to side, over the lines and up and down the pages. Further, the most delicately adjusted and rapid movements of the muscles of the lips, tongue, and throat, of the laryngeal and respiratory muscles, are involved in the production of speech. Perhaps the reader is standing up and accompanying the lecture with appropriate gestures. And yet every one of these muscular acts may be performed with utter unconsciousness, on his part, of anything but the sense of the words in the book. In other words, they are reflex acts.

25. The reflex actions proper to the spinal cord itself are *natural*, and are involved in the structure of the cord and the properties of its constituents. By the help of the brain we may acquire an infinity of *artificial* reflex actions. That is to say, an action may require all our attention and all our volition for its first, or second, or third performance, but by frequent repetition it becomes, in a manner, part of our organization, and is performed without volition, or even consciousness.

As every one knows, it takes a soldier a long time to learn his drill—for instance, to put himself into the attitude of "attention" at the instant the word of command is heard. But, after a time, the sound of the word gives rise to the act, whether the soldier be thinking of it, or not. There is a story, which is credible enough, though it may not be true, of a practical joker, who, seeing a discharged veteran carrying home his dinner, suddenly called out "Attention!" whereupon the man instantly brought his hands down, and lost his mutton and potatoes in the gutter. The drill had been thorough, and its effects had become embodied in the man's nervous structure.

The possibility of all education (of which military drill is only one particular form) is based upon the existence of this power which the nervous system possesses, of organizing conscious actions into more or less unconscious, or reflex, operations. It may be laid down as a rule, that, if any two mental states be called up together, or in succession, with due frequency and vividness, the subsequent production of the one of them will suffice to call up the other, and that whether we desire it or not.

The object of intellectual education is to create such indissoluble associations of our ideas of things, in the order and relation in which they occur in nature; that of moral education is to unite, as fixedly, the ideas of evil deeds with those of pain and degradation, and of good actions with those of pleasure and nobleness.

26. The *sympathetic system* consists chiefly of a double chain of ganglia, lying at the sides and in front of the spinal column, and connected with one another, and with the spinal nerves, by commissural

cords. From these ganglia nerves are given off which for the most part follow the distribution of the vessels, but which, in the thorax and abdomen, form great networks, or *plexuses*, upon the heart and about the stomach. It is probable that a great proportion of the fibres of the sympathetic system is derived from the spinal cord; but others also, in all probability, originate in the ganglia of the sympathetic itself. The sympathetic nerves influence the muscles of the vessels generally, and those of the heart, of the intestines, and of some other viscera; and it is probable that their ganglia are centres of reflex action to afferent nerves from these organs. But many of the motor nerves of the vessels are, as we have seen, under the influence of particular parts of the spinal cord, though they pass through sympathetic ganglia.

LESSON XII.

HISTOLOGY; OR, THE MINUTE STRUCTURE OF THE TISSUES.

1. THE various organs and parts of the body, the working of which has now been described, are not merely separable by the eye and the knife of the anatomist into membranes, nerves, muscles bones, cartilages, and so forth; but each of them is susceptible of a finer analysis, by the help of the microscope, into certain minute constituents which, for the present, are the ultimate structural elements of the body.

2. There is a time when the human body, or rather its rudiment, is of one structure throughout, consisting of a more or less transparent *matrix*, through which are scattered minute rounded particles of a different optical aspect. These particles are called *nuclei;* and as the matrix, or matter in which these nuclei are imbedded, readily breaks up into spheroidal masses, one for each nucleus, and these investing masses easily take on the form of vesicles or *cells,* this primitive structure is called *cellular,* and each cell is said to be *nucleated.*

As development goes on, the nuclei of this *indifferent tissue* simply increase in number, by division and subdivision; but the substance in which they are imbedded, commonly called the *cell wall* and *intercellular substance,* becomes very variously modified, both chemically and structurally, and gives rise to the peculiarities by which completely formed tissues are distinguished from one another.

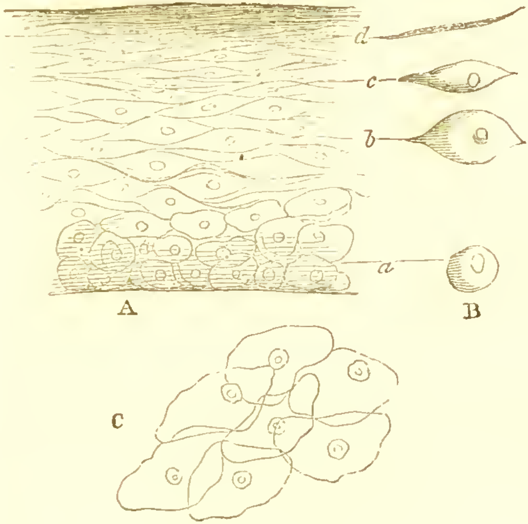

FIG. 74.

A, vertical section of a layer of epidermis, or epithelium, from its free to its deep surface; B, lateral views of the cells of which this layer is composed at the different heights, *a b c d*; C, scales such as *d* viewed from their flat sides. Magnified about 250 diameters.

3. Among these, the *epidermis* and some forms of *epithelium* present the simplest structure, next to the blood and lymph corpuscles described above (Lesson III.). These tissues are constantly growing in their deepest parts, and are, as constantly, being shed at their surfaces.

The deep part consists of a layer of such globular nucleated cells as have been mentioned, the number of which is constantly increasing by the spontaneous division of the nuclei and cells. The increase in number thus effected causes a thrusting of the excess of cell population towards the surface; on their way to which they become flattened, and their walls acquire a horny texture. Arrived at the surface, they are mere dead horny scales, and are thrown off (Fig. 74).

Epithelium of the kind just described is called *squamous.* It is found in the mouth, and its scales may always be obtained in abundance by scraping the inside of the lip.

In other parts of the alimentary tract, as in the intestines, the full-grown epithelial cells are placed side by side with one another, and perpendicular to the surface of the membrane. Such epithelium is called *cylindrical* (Fig. 75).

In some glands, such as the gastric glands, the epithelial cells remain *globular.*

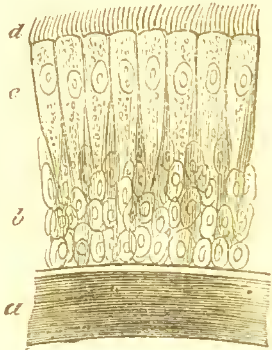

Fig. 75.

Ciliated epithelium.—*a*, the submucous vascular tissue; *b*, the deep layer of young epithelium cells; *c*, the cylindrical full-grown cells, with (*d*) the cilia. Magnified about 350 diameters.

Ciliated epithelium is usually of the cylindrical kind, and differs from other epithelium only in the circumstance that one, or more, incessantly vibrating filaments are developed from the free surface of each cell.

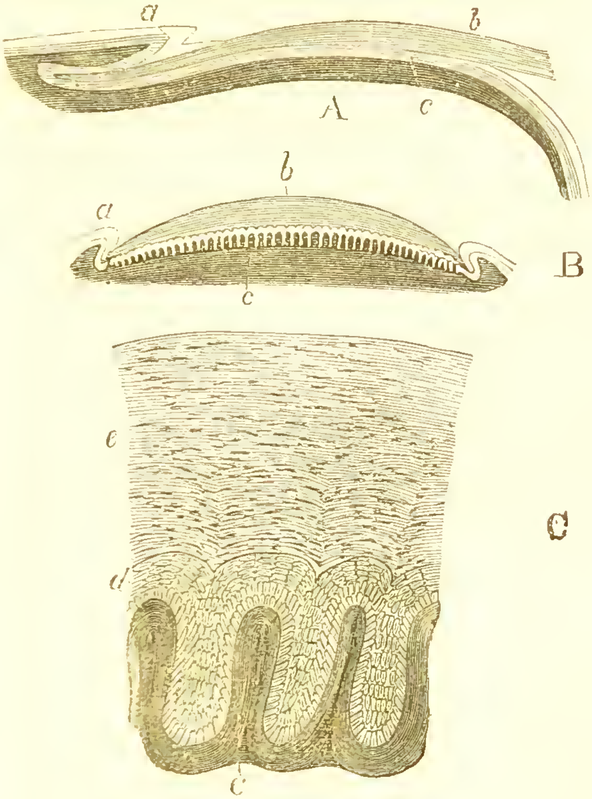

FIG. 76.

A, a longitudinal and vertical section of a nail: *a*, the fold at the base of the nail; *b*, the nail; *c*, the bed of the nail. The figure B is a transverse section of the same—*a*, small lateral folds of the integument; *b*, nail; *c*, bed of the nail, with its ridges. The figure C is a highly-magnified view of a part of the foregoing—*c*, the ridges; *d*, the deep layers of epidermis; *e*, the horny scales coalesced into nail substance. Figs. A and B magnified about 4 diameters; Fig. C, magnified about 200 diameters.

4. In certain regions of the integument, the epidermis becomes metamorphosed into *nails* and *hairs.*

Underneath each nail the deep layer of the integument is peculiarly modified to form the *bed of the nail.* It is very vascular, and raised up into numerous parallel ridges, like elongated papillæ (Fig. 76, B, C). The surfaces of all these are covered with growing epidermic cells, which, as they flatten and become converted into horn, coalesce into a solid continuous plate, the nail. At the hinder part of the bed of the nail, the integument forms a deep fold, from the bottom of which, in like manner, new epidermic cells are added to the base of the nail, which is thus constrained to move forward.

The nail, thus constantly receiving additions from below and from behind, slides forwards over its bed, and projects beyond the end of the finger, where it is worn away, or cut off.

5. A *hair,* like a nail, is composed of coalesced horny cells, but instead of being only partially sunk in a fold of the integument, it is at first wholly inclosed in a kind of bag, the *hair sac,* from the bottom of which a papilla, which answers to a single ridge of the nail, arises. The hair is developed by the conversion into horn, and coalescence into a *shaft,* of the superficial epidermic cells coating the papilla. These coalesced and cornified cells being continually replaced by new growths from below, which undergo the same metamorphosis, the shaft of the hair is thrust out until it attains the full length natural to it. Its base then ceases to grow, and the old papilla and sac die away, but not before a new sac and papilla have been formed by budding from the sides of the old one. These give rise to a new

hair. The shaft of a hair of the head consists of a central pith, or *medullary* matter, of a loose and open texture, which sometimes contains air; of a *cortical* substance surrounding this, made up of coalesced elongated horny cells; and of an outer *cuticle*, composed of flat horny plates, arranged transversely round the shaft, so as to overlap one another by their outer edges, like closely-packed tiles. The superficial epidermic cells of the hair-sac also coalesce by their edges, and become converted into sheaths, which embrace the root of the hair, and usually come away with it, when it is plucked out.

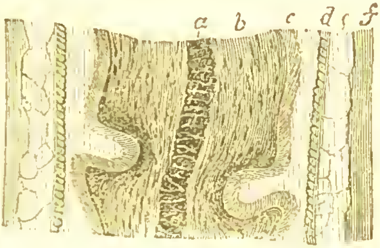

FIG. 77.

Part of the shaft of a hair inclosed within its sac and treated with caustic soda, which has caused the shaft to become distorted.—*a*, medulla; *b*, cortical part; *c*, cuticle of the shaft; *d* and *e*, inner and outer root sheaths; *f*, wall of the hair sac. Magnified about 200 diameters.

Two sebaceous glands commonly open into the hair-sac near its opening, and supply the hair with a kind of natural pomatum; and delicate unstriped muscular fibres are so connected with the hair-sac as to cause it to pass from its ordinary oblique position into one perpendicular to the skin, when they contract (Fig. 28, B).

They are made to contract by the influence of cold and terror, which thus give rise to "horripilation" or "goose-skin," and the "standing of the hair on end."

6. The *crystalline lens* is composed of fibres, which are the modified cells of the epidermis of that inverted portion of the integument, from which the whole anterior chamber of the eye and the lens are primitively formed.

7. *Cartilage.* While *epithelium* and *epidermis* are found only on the free surfaces of the organs, gristle, or cartilage, is a deep-seated structure (see Lesson VII.). It is composed of a semi-transparent, resisting, elastic matter, which yields the substance called *chondrine* by boiling, and contains a great number of minute cavities, in which lie single nucleated cells, or groups of such cells (Fig. 78). These cells increase in number by division. Cartilage contains no vessels, or only such as extend into it from adjacent parts.

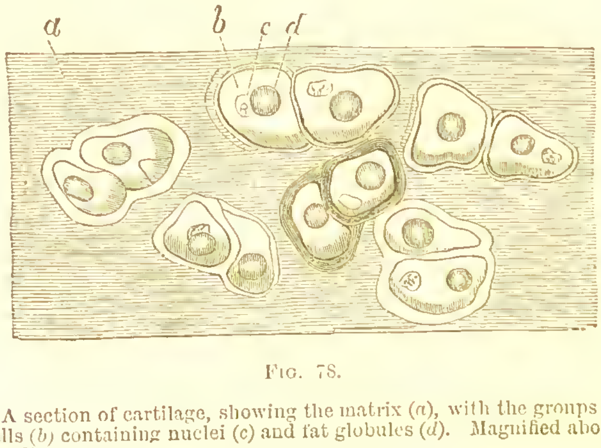

Fig. 78.

A section of cartilage, showing the matrix (*a*), with the groups of cells (*b*) containing nuclei (*c*) and fat globules (*d*). Magnified about 350 diameters.

8. *Connective Tissue* (also called *fibrous*, or *areolar*, or sometimes *cellular* tissue).

This tissue, the most extensively diffused of all in the body, consists of bands or cords, or sheets of whitish substance, having a wavy fibrous appearance, and capable of being split up mechanically into innumerable fine filaments. It swells up and yields *gelatine* when it is boiled in water.

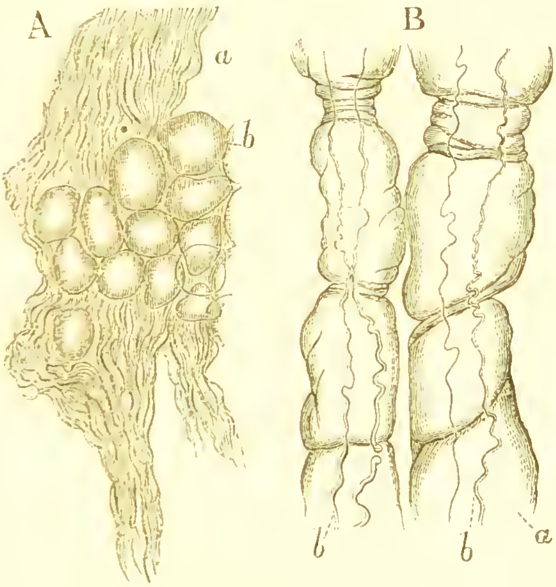

FIG. 79.

Connective tissue.—A, unchanged—*a*, connective tissue; *b*, fat cells: B, acted upon by acetic acid, and showing (*a*) the swollen and transparent gelatine-yielding matter, and (*b*) the elastic fibres. Magnified about 300 diameters.

The addition of strong acetic acid also causes it to swell up and become transparent, entirely losing its fibrous aspect; and, further, reveals the presence of two elements which acetic acid does not affect, viz. nuclei and elastic fibres of different degrees of fineness. If the acid be now neutralized by a weak alkali, the connective tissue assumes its former partial opacity and fibrillated aspect. The nuclei are the descendants of those which existed in the indifferent tissue from which the connective tissue has proceeded—while the elastic fibres, like the gelatine-yielding fibres, proceed from the metamorphosis of the matrix. The proportion of elastic fibre to the gelatine-yielding constituents of connective tissue varies, in different parts of the body. Sometimes it is so great that elasticity is the most marked character of the resulting tissue.

Ligaments and tendons are simply cords, or bands, of very dense connective tissue. In some parts of the body the connective tissue is more or less mixed with, or passes into, cartilage, and such tissues are called *fibro-cartilages* (see Lesson VII.).

9. *Fat Cells* are scattered through the connective tissue, in which they sometimes accumulate in great quantities. They are spheroidal sacs, composed of a delicate membrane, on one side of which is a nucleus, and distended by fatty matter, from which the more solid fats sometimes crystallize out after death. Ether will dissolve out the fat, and leave the sacs empty and collapsed (Fig. 80).

Considerable aggregations of fat cells are constantly present in some parts of the body, as in the orbit, and about the kidneys and heart; but elsewhere their presence, in any quantity, depends very much on the state of nutrition. Indeed, they may be regarded simply as a reserve, formed from the nutriment which has been taken into the body in excess of its average consumption.

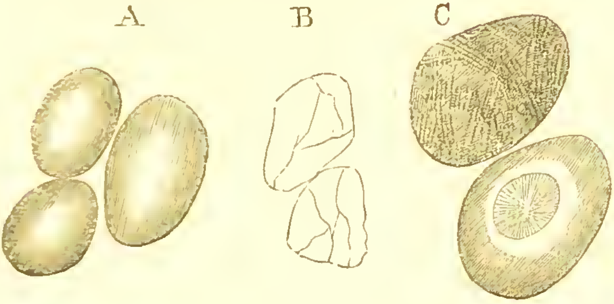

FIG. 80.

Fat cells.—A, having their natural aspect; B, collapsed, the fat being exhausted; C, with fatty crystals. Magnified about 350 diameters.

10. *Pigment Cells* are either epidermic or epithelial cells, in which coloured granules are deposited, or they are particular cellular elements of the deeper parts of the body, in which a like deposit occurs. Thus the colour of the choroid and of the iris arises from the presence of a layer of such cells.

11. *Bone* is essentially composed of an animal basis impregnated with salts of carbonate and phosphate of lime, through the substance of which are scattered minute cavities—the *lacunæ*, which send out multitudinous ramifications, called *canaliculi*. The canaliculi of different lacunæ unite together, and thus establish a communication between the different lacunæ. If the earthy matter be extracted by dilute acids, a nucleus is constantly

found in each lacuna; and, not unfrequently, the intermediate substance appears minutely fibrillated. In a dry bone the lacunæ are usually filled with air. When a thin section of such a bone is, as usual, covered with water and a thin glass, and placed under the microscope, the air in the lacunæ refracts the light which passes through them, in such a manner as to prevent its reaching the eye, and they appear black. Hence the lacunæ were, at one time, supposed to be solid bodies, containing the lime salts of the bone, and were called *bone corpuscles* (Fig. 81, C).

All bones, except the smallest, are traversed by small canals, converted by side branches into a network, and containing vessels supported by more or less connective tissue and fatty matter. These are called *Haversian canals* (Fig. 81, A, B). They always open, in the long run, upon the surface of the bone, and there the vessels which they contain become connected with those of a sheet of tough connective tissue, which invests the bone, and is called *periosteum.*

In many long bones, such as the thigh bone, the centre of the bone is hollowed out into a considerable cavity, containing great quantities of fat, supported by a delicate connective tissue, rich in blood-vessels, and called the *marrow,* or *medulla.* The inner ends of the Haversian canals communicate with this cavity, and their vessels are continuous with those of the marrow.

When a section of a bone containing Haversian canals is made, it is found that the lacunæ are dispersed in concentric zones around each Haversian canal, so that the substance of the bone appears laminated; and, where a medullary cavity exists,

FIG. 81.

A. A transverse section of bone in the neighbourhood of two Haversian canals, *a a*; *b*, lacunæ. Magnified about 250 diameters.

B. A longitudinal section of bone with Haversian canals, *a a*, and lacunæ, *b*. Magnified about 100 diameters.

C. Lacunæ, *c*, and canaliculi, *d*. Magnified about 600 diameters.

more or fewer of these concentric lamellæ of osseous substance surround it.

This structure arises from the mode of growth of bones. In the place of every bone there exists, at first, either cartilage, or connective tissue hardly altered from its primitive condition of indifferent tissue. When *ossification* commences, the vessels from the adjacent parts extend into the ossifying tissue, and the calcareous salts are thrown down around them. These calcareous salts invade all the ossifying tissue, except the immediate neighbourhood of its nuclei, around each of which a space, the *lacuna*, is left. The lacunæ and canaliculi are thus, substantially, gaps left in the ossific matter around each nucleus, whence it is that nuclei are found in the lacunæ of fully-formed bone.

Bone, once formed, does not remain during life, but is constantly disappearing and being replaced in all its parts. Nevertheless, the growth of a bone, as a general rule, takes place only by addition to its free ends and surfaces. Thus the bones of the skull grow in thickness, on their surfaces, and in breadth at their edges, where they unite by *sutures ;* and when the sutures are once closed, they cease to increase in breadth.

The bones of the limbs, which are preceded by complete cartilaginous models, grow in two ways. The cartilage of which they consist grows and enlarges at its extremities until the bones have attained their full size, and remains to the end of life as *articular cartilage*. But in the middle, or shaft, of the bone, the cartilage does not grow with the increase in the dimensions of the bone, but becomes coated by successive layers of bone, produced by the ossification of that part of the periosteum which lies nearest to the cartilage. The shaft of the bone thus formed is gradually hollowed out in its interior to form the medullary cavity, so that, at last, the primitive cartilage totally disappears.

When ossification sets in, the salts of lime are not diffused uniformly through the whole mass of the pre-existing cartilage, or connective tissue, but begin to be deposited at particular points called *centres of ossification,* and spread from them through the bone. Thus, a long bone has usually, at fewest, three centres of ossification—one for the middle or shaft, and one for each end; and it is only in adult life that the three bony masses thus formed unite into one bone.

12. *Teeth* partake more of the nature of bones than of any other organ, and are, in fact, partially composed of true bony matter, here called *cement;* but their chief constituents are two other tissues, called *dentine* and *enamel.*

Each tooth presents a crown, which is exposed to wear, and one or more fangs, which are buried in a socket furnished by the jawbone and the dense mucous membrane of the mouth, which constitutes the *gum.* The line of junction between the crown and the fang is the *neck* of the tooth. In the interior of the tooth is a cavity, which communicates with the exterior by canals, which traverse the fangs and open at their points. This cavity is the *pulp cavity.* It is occupied by a highly-vascular and nervous tissue, the *dental pulp,* which is continuous below, through the openings of the fangs, with the mucous membrane of the gum.

The chief constituent of a tooth is *dentine*—a dense calcified substance containing less animal matter than bone, and further differing from it in possessing no lacunæ, or proper canaliculi. Instead of these it presents innumerable, minute, parallel, wavy tubules, which give off lateral branches. The wider ends of these tubules open into the pulp cavity, while the narrower ultimate terminations ramify at the surface of the dentine, and may even extend into the enamel or cement (Fig. 83, C).

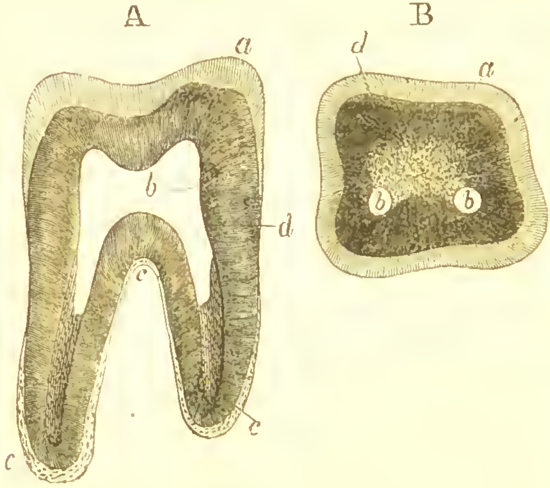

FIG. 82.

A, vertical, B, horizontal section of a tooth.—*a*, enamel of the crown; *b*, pulp cavity; *c*, cement of the fangs; *d*, dentine. Magnified about three diameters.

The *enamel* consists of very small six-sided fibres, set closely, side by side, at right angles to the surface of the dentine, and covering the crown of the tooth as far as the neck, towards which the enamel thins off and joins the cement (Fig. 83, A, B).

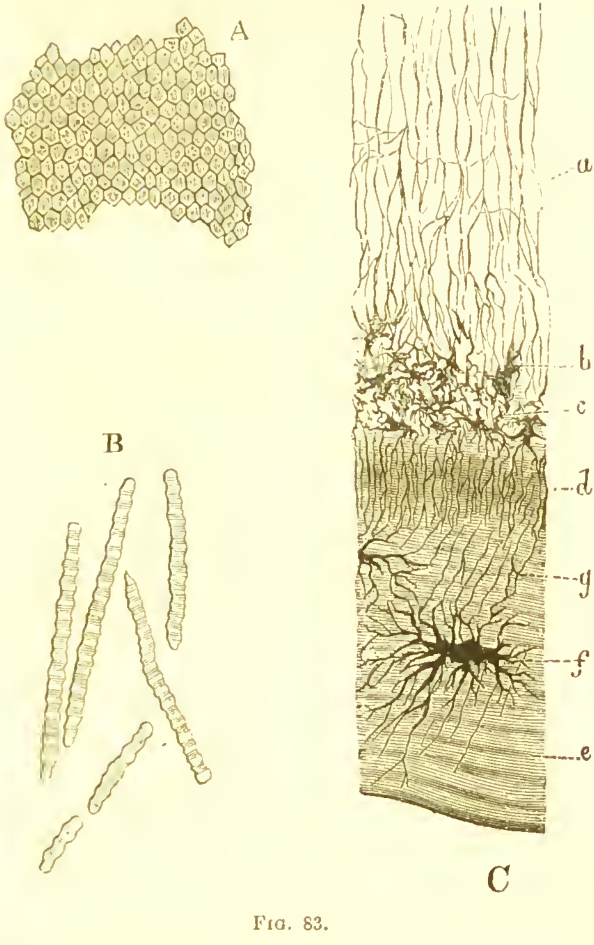

FIG. 83.

A. Enamel fibres viewed in transverse section.
B. Enamel fibres separated and viewed laterally.
C. A section of a tooth at the junction of the dentine (*a*) with the cement (*e*); *b c*, irregular cavities in which the tubules of the dentine end; *d*, fine tubules continued from them; *f g*, lacunæ and canaliculi of the cement. Magnified about 400 diameters.

Enamel is the hardest tissue of the body, and contains not more than 2 per cent. of animal matter.

The *cement* coats the fangs, and has the structure of true bone; but as it exists only in a thin layer, it is devoid of Haversian canals (Fig. 83, C).

13. The development of the teeth commences long before birth. A groove appears in the gum of each side of each jaw; and, at the bottom of this groove of the gum, five vascular and nervous *papillæ* arise, making twenty in all. The walls of the groove grow together, between and over each of the papillæ, and thus these become inclosed in what are called the *dental sacs.*

Each papilla gradually assumes the form of the future tooth. Next a deposit of calcific matter takes place at the summit of the papilla, and extends thence, downwards, towards its base. In the crown the deposit takes on the form of enamel and dentine; in the root, of dentine and cement. As it increases it encroaches upon the substance of the papilla, which remains as the tooth pulp. The fully formed teeth press upon the upper walls of the sacs in which they are inclosed, and, causing a more or less complete absorption of these walls, force their way through. The teeth are then, as it is called, *cut.*

The cutting of this first set of teeth, called *deciduous,* or *milk teeth,* commences at about six months, and ends with the second year. They are altogether twenty in number—eight being cutting teeth, or *incisors;* four, eye teeth, or *canines;* and eight, grinders, or *molars.*

Each dental sac of the milk teeth, as it is formed, gives off a little prolongation, which becomes lodged in the jaw, enlarges, and develops a papilla from which a new tooth is formed. As the latter increases in size it presses upon the root of the milk tooth which preceded it, and thereby causes the absorption of the root and the final falling out, or shedding, of the milk tooth, whose place it takes. Thus every milk tooth is replaced by a tooth of what is termed the *permanent dentition.* The permanent *incisors* and *canines* are larger than the milk teeth of the same name, but otherwise differ little from them. The permanent molars, which replace the milk molars, are small, and their crowns have only two points, whence they are called *bicuspid.* They never have more than two fangs.

14. We have thus accounted for twenty of the teeth of the adult. But there are thirty-two teeth in the complete adult dentition, twelve grinders being added to the twenty teeth which correspond with, and replace, those of the milk set. When the fifth, or hindermost, dental sac of the milk teeth is formed, the part of the groove which lies behind it also becomes covered over, extends into the back part of the jaw, and becomes divided into three dental sacs. In these, papillæ are formed, and give rise to the great permanent back grinders, or *molars,* which have four, or five, points upon their square crowns, and, in the upper jaw, commonly possess three fangs.

The first of these teeth, the anterior molar of each side, is the earliest cut of all the permanent set, and appears at six years of age. The last, or hindermost, molar is the last of all to be cut, usually not appearing till twenty-one or twenty-two years of age. Hence it goes by the name of the "wisdom tooth."

15. *Muscle* is of two kinds, *striated* and *smooth.*

Striated muscle, of which all the ordinary muscles of the trunk and limbs consist, is composed of bundles of fibres, usually united at their ends to cords or sheets of connective tissue—the *tendons* (see Lesson VII.). The bundles are enveloped in, and bound together by, connective tissue, which supports the vessels and nerves of the muscle, and sometimes forms a dense sheath on its exterior, called a *fascia*.

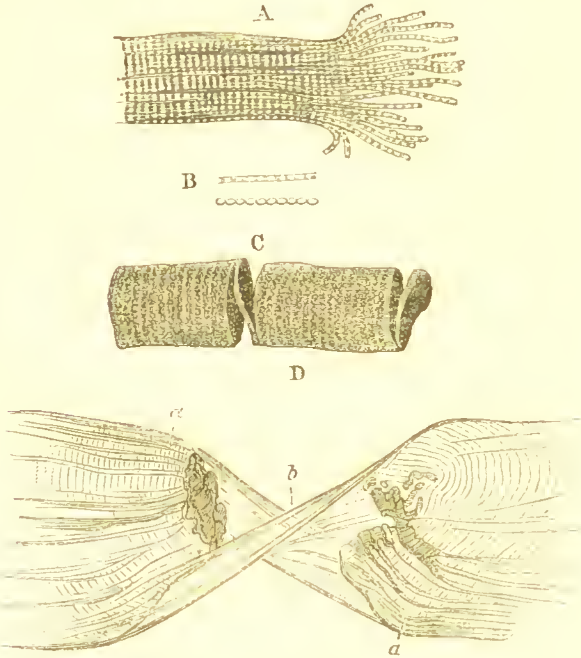

Fig. 84.

A, a muscular fibre, devoid of sarcolemma, and breaking up at one end into its *fibrillæ;* B, separate fibrillæ; C, a muscular fibre breaking up into disks; D, a muscular fibre, the contractile substance of which (*a*) is torn, while the sarcolemma (*b*) has not given way. Magnified about 350 diameters.

Into the ultimate *striated muscular fibre* neither vessels, nor connective tissue, enter. Each fibre is, in fact, enveloped in a sheath formed by a tough, elastic, transparent, structureless membrane, the *sarcolemma* (Fig. 84).

The sarcolemma is not contractile, but its elasticity allows it to adjust itself, pretty accurately, to the changes of form of the contractile substance which it contains.

This contractile substance, when uninjured, presents a very strongly-marked transverse striation, its substance appearing to be composed of disks of a partially opaque substance, in regular alternation with others of a more transparent matter. A more faint longitudinal striation is also observable. When the sarcolemma is torn, the contractile substance either divides into disks (Fig. 84, C), or more frequently and readily breaks up into minute *fibrillæ* (Fig. 84, A, B), each of which, viewed by transmitted light, presents dark and light parts, which alternate at intervals exactly corresponding with the distances of the transverse striæ in the entire fibre. Nuclei are observed here and there in the contractile substance within the sarcolemma.

In the heart, the muscular fibres are striated, and have the same essential structure as that just described, but they possess no sarcolemma.

Smooth muscle consists of elongated band-like fibres, devoid of striation, each of which bears a rod-like nucleus. These fibres do not break up into fibrillæ, and have no sarcolemma (Fig. 85, B).

16. *Nervous tissue* contains two elements, *nerve-fibres* and *ganglionic corpuscles.* Ordinary nerve-fibres, such as constitute the essential constituents of all but the olfactory nerves, are during life, or

when perfectly fresh, subcylindrical filaments of a clear, somewhat oily, look. But shortly after death, a sort of coagulation sets up within the fibre, and it is then found to be composed of a very delicate

Fig. 85.

A, a nerve-fibre in its fresh and unaltered condition; B, a nerve-fibre in which the greater part of the sheath and coagulated contents (*a b*) have been stripped off from the axis cylinder (*c c*); C, a nerve-fibre, the upper part of which retains its sheath and coagulated contents, while the axis cylinder (*a a*) projects; D, a ganglionic corpuscle—*a*, its nucleus and nucleolus. Magnified about 350 diameters.

structureless outer membrane (which is not to be confounded with the *neurilemma*), forming a tube, through the centre of which runs a solid filament, the *axis cylinder*. Between the axis cylinder and the tube is a fluid, from which a solid strongly refracting matter has been thrown down and lines the tube.

Such is the structure of all the larger nerve-fibres, which lie, side by side, in the trunks of the nerves, bound together by delicate connective tissue, and inclosed in a sheath of the same substance, called the *neurilemma*. In the trunks of the nerves the fibres remain perfectly distinct from one another, and rarely, if ever, divide. But when the nerves enter the central organs, aud when they approach their peripheral terminations, the nerve-fibres frequently divide into branches. In any case they become gradually finer and finer; until at length, axis-cylinder, sheath, and contents are not separable, aud the nerve becomes a homogeneous filament, the ultimate termination of which, in the sensory orgaus and in the muscles, is not yet satisfactorily made out.

17. In Lesson VIII. mention is made of peculiar bodies called *tactile corpuscles*, which are oval masses of specially modified connective tissue in relation with the ends of the nerves in the papillæ of the skin. In Fig. 86 four such papillæ, which have been rendered transparent and stripped of their epidermis, are seen, and the largest contains a tactile corpuscle (*e*).

In the brain and spinal cord, on the other hand, it is certain that, in many cases, the fine ends of the nerve-fibres are continued into the processes of the ganglionic corpuscles.

18. The *olfactory nerves* are pale flat fibres, without any distinction into axis, cylinder, and contents, but with nuclei set at intervals along their length.

FIG. 86.

Papillæ of the skin of the finger.—*a*, a large papilla containing a tactile corpuscle (*c*) with its nerve (*d*); *b*, other papillæ, without corpuscles, but containing loops of vessels, c. Magnified about 300 diameters.

19. *Ganglionic corpuscles* are chiefly found in the cerebro-spinal axis; in the ganglia of the posterior nerve roots, and in those of the sympathetic; but they occur also elsewhere, notably in some of the sensory organs (see Lesson IX.).

They are spheroidal bodies, containing a central cavity, in which a nucleus lies (Fig. 85, D. *a*). Each sends off one, two, or more prolongations, which may divide and subdivide; and which, in some cases, unite with the prolongations of other ganglionic corpuscles, while, in others, they are continued into nerve-fibres.

A TABLE OF ANATOMICAL AND PHYSIOLOGICAL CONSTANTS.

The average weight of the human body may be taken at 154 lbs.

I. General Statistics.

Such a body would be made up of—

	lbs.
Muscles and their appurtenances	68
Skeleton	24
Skin	10½
Fat	28
Brain	3
Thoracic viscera	2½
Abdominal viscera	11
	147*

	lbs.
Or of water	88
Solid matters	66

* The addition of 7 lbs. of blood, the quantity which will readily drain away from the body, will bring the total to 154 lbs. A considerable quantity of blood will, however, always remain in the capillaries and small blood vessels, and must be reckoned with the various tissues. The total quantity of blood in the body is now calculated at about 1-13th of the body weight, *i.e.*, about 12 lbs.

The solids would consist of the elements oxygen, hydrogen, carbon, nitrogen, phosphorus, sulphur, silicon, chlorine, fluorine, potassium, sodium, calcium (lithium), magnesium, iron (manganese, copper, lead), and may be arranged under the heads of—

Proteids. Amyloids. Fats. Minerals.

Such a body would lose in 24 hours—of water, about 40,000 grains, or 6 lbs.; of other matters about 14,500 grains, or over 2 lbs.; among which of carbon 4,000 grains; of nitrogen 300 grains; of mineral matters 400 grains; and would part, per diem, with as much heat as would raise 8,700 lbs. of water from 0° to 1° Fahr., which is equivalent to 3,000 foot-tons.[1] Such a body ought to do as much work as is equal to 450 foot-tons.

The losses would occur through various organs, thus—by

	WATER. grs.	OTHER MATTER. grs.	N grs.	C. grs.
Lungs . .	5,000	12,000	...	3,300
Kidneys . .	23,000	1,000	250	140
Skin . . .	10,000	700	10	100
Fæces . .	2,000	800	40	460
Total . .	40,000	14,500	300	4,000

The *gains* and *losses* of the body would be as follows:—

		grs.
Creditor—	Solid dry food . . .	8,000
	Oxygen	10,000
	Water	36,500
	Total	54,500

[1] A foot-ton is the equivalent of the work required to lift one ton one foot high.

		grs.
Debtor —	Water	40,000
	Other Matters	14,500
	Total	54,500

II. Digestion.

Such a body would require for daily food, carbon 4.000 grains; nitrogen 300 grains, which, with the other necessary elements, would be most conveniently disposed in—

	grs.
Proteids	2,000
Amyloids	4,400
Fats	1,200
Minerals	400
Water	36,500
Total	44,500

which, in turn, might be obtained, for instance, by means of—

	grs.
Lean beefsteaks	5,000
Bread	6,000
Milk	7,000
Potatoes	3,000
Butter, dripping, &c.	600
Water	22,900
Total	44,500

The fæces passed, per diem, would amount to about 2,800 grains, containing solid matter, 800 grains.

III. Circulation.

In such a body, the heart would beat 75 times a minute, and probably drive out, at each stroke from each ventricle, from 5 to 6 cubic inches, or about 1,500 grains of blood.

The blood would probably move in the great arteries at a rate of about 12 inches in a second, in the capillaries at 1 to $1\frac{1}{2}$ inches in a minute; and the time taken up in performing the entire circuit would probably be about 30 seconds.

The left ventricle would probably exert a pressure on the aorta equal to the pressure on the square inch of a column of blood about 9 feet in height; or of a column of mercury about $9\frac{1}{2}$ inches in height; and would do in 24 hours an amount of work equivalent to about 90 foot-tons; the work of the whole heart being about 120 foot-tons.

IV. Respiration.*

Such a body would breathe 15 times a minute.

The lungs would contain of residual air about 100 cubic inches, of supplemental or reserve air about 100 cubic inches, of tidal air 20 to 30 cubic inches, and of complemental air 100 cubic inches.

The vital capacity of the chest, that is, the greatest quantity of air which could be inspired or expired, would be about 230 cubic inches.

There would pass through the lungs, per diem, about 350 cubic feet of air.

In passing through the lungs, the air would lose from 4 to 6 per cent. of its volume of oxygen, and gain 4 to 5 per cent. of carbonic acid.

During 24 hours there would be consumed about

10,000 grains oxygen; and produced about 12,000 grains carbonic acid, corresponding to 3,300 grains carbon. During the same time about 5,000 grains or 9 oz. of water would be exhaled by the lungs.

In 24 hours such a body would vitiate 1750 cubic feet of pure air to the extent of 1 per cent. or 17,500 cubic feet of pure air to the extent of 1 per 1,000. Taking the amount of carbonic acid in the atmosphere at 3 parts, and in expired air at 470 parts in 10,000, such a body would require a supply per diem of more than 23,000 cubic feet of ordinary air, in order that the surrounding atmosphere might not contain more than 1 per 1,000 of carbonic acid (when air is vitiated from animal sources with carbonic acid to more than 1 per 1,000, the concomitant impurities become appreciable to the nose). A man of the weight mentioned (11 stone) ought, therefore, to have at least 800 cubic feet of well ventilated space.

V. Cutaneous Excretion.

Such a body would throw off by the *skin*—of water about 18 ounces, or 10,000 grains; of solid matters about 300 grains; of carbonic acid about 400 grains, in 24 hours.

VI. Renal Excretion.

Such a body would pass by the *kidneys*—of water about 50 ounces; of urea about 500 grains; of other solid matters about 500 grains, in 24 hours

VII. Nervous Action.

In the frog a nervous impulse travels at the rate of about 80 feet in a second.

In man a nervous (sensory) impulse has been variously calculated to travel at 100, 200, or 300 feet in a second.

VIII. Histology.

Red corpuscles of the blood are about $\frac{1}{3200}$th of an inch in breadth; white corpuscles $\frac{1}{2500}$th.

Striated muscular fibres are about $\frac{1}{400}$th of an inch in breadth; plain $\frac{1}{4000}$th.

Nerve-fibres vary between $\frac{1}{1500}$th and $\frac{1}{12000}$th of an inch in breadth.

Connective tissue fibrils are about $\frac{1}{40000}$th of an inch in breadth.

Epithelium scales (of the skin) are about $\frac{1}{500}$th of an inch in breadth.

Capillary blood-vessels are from $\frac{1}{3500}$th to $\frac{1}{2000}$th of an inch in breadth.

Cilia (from the wind-pipe) are about $\frac{1}{3000}$th of an inch in length.

The cones in the "yellow spot" of the retina are about $\frac{1}{10000}$th of an inch in breadth.

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